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MAINTAINING AMERICA'S SCIENTIFIC PRODUCTIVITY:

The Necessity of the Liberal Arts Colleges

by

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INTRODUCTION

This report presents the second year's research on the condition and needs of the sciences at leading liberal arts colleges. These schools were identified on the basis of a composite index of several measures of productivity and promise in training and research in undergraduate science. It is the final version of the report published in preliminary form for the second conference on "The Future of Science at Liberal Arts Colleges", held in June, 1986. Like its predecessor (Educating America's Scientists: The Role of the Research Colleges, June, 1985), the present study was conducted at Oberlin College by Sam C. Carrier and David Davis-Van Atta. Funding for the study, including the collection and analysis of the data on which it is based, were provided completely by the colleges themselves.

Certain conclusions from this report stand out. THE MOST IMPORTANT IS THAT OVER THE NEXT DECADE AMERICA'S TOP LIBERAL ARTS COLLEGES MUST INVEST A TOTAL OF ONE BILLION DOLLARS ABOVE CURRENT COMMITMENTS IF THEY ARE TO MAINTAIN AND ENHANCE THEIR PRESENT POSITION IN BASIC SCIENCE EDUCATION AND RESEARCH.

A major objective of the current research was to gain further insight into the educational productivity of the college-based science programs. In other words, how good are the graduates? The evidence clearly indicates that the participating institutions are very strong in this regard, indeed, fully competitive with the undergraduate programs of the nation's leading research universities. The strength is both quantitative and qualitative. The volume

of bachelor's degrees conferred at the schools participating in the study grew slightly in 1985, in the face of continued decline nationally and at the major universities. The preparation of women scientists remains a particular strength of the colleges.

Within the group of four dozen plus participating colleges, there is a sub-group of perhaps a dozen whose record in the training of scientists is particularly outstanding. These institutions stand fully on par with leading research universities, and, in many instances, exceed them both in the quality of science graduates (as measured by career distinction), and in their quantity (as a percentage of all graduates).

Given both the qualitative and quantitative indicators of the production of scientists at the participating colleges, it is clear that these liberal arts institutions make a significant and increasingly important contribution to America's scientific manpower pool at a time when this critical national resource is generally declining.

What is needed to sustain and build this record? This study concludes that a collective capital investment of one billion dollars over the next ten years will be essential. Such a program assumes a conservative 1.1% annual growth in teaching staff, even though a growth of an additional 0.4% per annum will likely be required to handle increasing numbers of new majors and new fields. A 1.1% growth itself requires 160 new faculty positions per year, as well as the laboratory, library, research funding, and other supporting resources necessary to sustain the effectiveness of those teachers and practicing scientists.

The second major element of the one billion dollar investment is support for careers of faculty. Not only will market conditions drive up salaries, but they will also make it necessary for colleges to provide increased career support, including start-up costs of research and leaves for junior faculty.

The other two major components of the one billion dollar investment are laboratory instrumentation and basic physical facilities. Our study has found that a sum of 35 million dollars is needed immediately for basic pedagogical and research equipment, and 7 million dollars annually thereafter.

Equally striking is the large investment needed in existing buildings and facilities. Many will have to be remodeled. Many others will soon require outright replacement. It is our impression that the colleges themselves have generally ignored, or been unable to meet, this need, which will require approximately 150 million dollars over the coming ten years.

The fundamental conclusion of this study is that the colleges, individually and together, should launch capital campaigns to raise the billion needed. Just how this formidably enterprise is to be organized and conducted is a question that looms large.

One final conclusion should be noted. Last year's study revealed the exceptionally strong record of the participating colleges in the preparation of women scientists. This year's research notes the parallel between that strong record and the significant and growing cohort of women on the science faculties of these schools. Unfortunately, the colleges' record in the prepartion of young black scientists is not as strong, and is probably due in part to the

near total lack of black scientists, both men and women, on the science faculties of these schools. Even though this record is no worse than that of most research universities, it is nonetheless unacceptable. In addition to mounting campaigns to raise one billion dollars, the leading liberal arts colleges should undertake a special effort to train black and attract black faculty members in the basic sciences.

S. Frederick Starr

President, Oberlin College

Acknowledgements

All projects of this magnitude owe their success in some fundamental ways to a large cadre of individuals not charged primarily with the responsibilities of its completion. We wish to identify and thank many of these people here for their gracious and expert contributions, without which this report could not have been produced.

At Swarthmore College, Dr. Rush Holt, Department of Physics, performed a variety of critical services throughout the project. First, he was the Swarthmore delegate on the advisory panel to the principal investigators, a group which provided invaluable guidance to the project generally. His initial contacts at the National Academy of Sciences led to securing the data required for the analysis of the undergraduate origins of NAS members. Dr. Holt secured all of the necessary data from the Institute for Scientific Information (I.S.I.) to perform the analysis of the Science Citation Index presented here. This included collecting the basic data, manually searching out the undergraduate origins of 1,000 highly-cited scientists, and exploring and communicating the many nuances of this study. We are deeply in Dr. Holt's debt.

The entire advisory panel also deserves substantial thanks for having braved winter travel, and taken time away from busy professional schedules, to meet in Oberlin once, and thereafter to review drafts and to be generally available for consultation. The other members of this group were Dr. David Booth, Associate Provost, Williams College; Dr. Francis DeToma, Department of Biology, Mount Holyoke College; Dr. Conrad Stanitski, Assistant to the President, Franklin and Marshall College; and Dr. Daniel Sullivan, then Vice President of Carleton College, now President of Allegheny College. Special appreciation is hereby given for the highly informed and absolutely essential advice Dr. Sullivan was able to contribute throughout this project.

A large number of persons external to the project and the participating colleges aided invaluably in the compilation of a great deal of public and private domain data we required. Katherine Kelly, of R.R. Bowker, provided advice and some direct assistance in electronically searching the data base of American Men and Women of Science. Fred Chatterton, of Marquis Who's Who, directly provided all of the necessary data from the Who's Who in Frontier Science and Technology membership data base. Jean Marterre, of the Office of the Home Secretary at the National Academy of Sciences, worked long hours while laboring on other impending projects to provide us with the undergraduate origins of selected members of the National Academy. Dr. Henry Small, of the I.S.I., worked with Dr. Holt to provide and interpret the very valuable Science Citation Index data. Mr. Jack Dusatko, of the National Center for Education Statistics, Department of Education, coordinated all the prepartion of machine-readable records for all post-secondary degrees conferred from 1976 through 1983. Ralph Kazarian, Terrance Porter, Douglass Chapin and Julia Diggs, of the National Science Foundation, located a variety of archival information on NSF Fellowship recipients. Carol Fuller, whose work is cited in this report, also deserves special gratitude, not just for her excellent work generally in correcting the undergraduate origins of post-war doctoral recipients for undergraduate size, but also for her generous and almost

immediate provision of undergraduate size data by institution by year for 70 institutions over 30 years.

At Oberlin, a number of members of the college were pressed into our service. Local science faculty provided advice at several points in the project and survey design stages. Robert Schively compiled and entered an enormous quantity of highly disparate data on individual science graduates' career paths. Michael Stepak prepared and entered all the data concerning scientific equipment and instrumentation received from each of the science departments of the participating colleges. Mr. Curtis Kendrick provided his technical expertise in on-line searching of the A.M.W.S. data base. And, of course, President Starr has continued throughout this project to provide the primary motivation and conceptual imagination for it. Ms. Lyn Boone, Ms. Connie Gardner, and Ms. Jane Nabakowski all performed numerous clerical and other behind-the-scenes work on the endless but essential communications and logistics involved.

However, chief assistance at Oberlin unquestionably was provided by Ms. Renee Monson, (O.C., '85). Her work in the position of Research Intern for the project quite definitely made most of the numerous analyses required for this project's success move from concept to reality. Her organizational efforts were also essential.

Finally, a special thanks must be extended to all the faculty and administration of the participating colleges for the hours and hours spent collecting, often by hand, collating and transcribing the voluminous information on these institutions required to begin to understand their role in the education of America's scientific and engineering personnel. Their great labors are hereby equally greatly appreciated. It is our hope that the product we have created from all the efforts of these and other people we turned to for assistance will be of a value and quality to make these efforts all worthwhile.

The authors

The 50 Liberal Arts Colleges
Participating in the Second National Conference on
"The Future of Science at Liberal Arts Colleges",
Oberlin College, Oberlin, Ohio, June 9 and 10, 1986

Albion College
Alma College
Amherst College
Antioch University
Barnard College
Bates College
Beloit College
Bowdoin College
Bryn Mawr College
Bucknell University
Carleton College
Colgate University
Colorado College
Davidson College
Denison University
DePauw University
Earlham College
Franklin and Marshall College
Grinnell College
Hamilton College
Hampton University
Harvey Mudd College
Haverford College
College of the Holy Cross
Hope College
Kalamazoo College
Kenyon College
Lafayette College
Macalester College
Manhattan College
Middlebury College
Mount Holyoke College
Oberlin College
Occidential College
Ohio Wesleyan University
Pomona College
Reed College
Smith College
St. Olaf College
Swarthmore College
Trinity College
Union College
Vassar College
Wabash College
Wellesley College
Wesleyan University
Wheaton College
Whitman College
Williams College
College of Wooster

Chapter I

Student Characteristics and Educational Outcomes

Our 1985 report[1] on the state of undergraduate science at 48[2] colleges of the liberal arts and sciences provided extensive data on student populations obtaining education in the basic sciences at these institutions. These 1985 data were principally quantitative in nature: they provided the first-order volumetric measurements of science at these colleges (e.g., number and proportion of freshmen intending science majors, number and proportion of baccalaureates awarded in science disciplines, proportion of women in the sciences, faculty size, etc.), and compared these data both to national norms, and to those of the undergraduate colleges of the nation's premier research universities.

These data, while impressive, must be supplemented with other critical measures of the contribution to American science made by liberal arts colleges, and of the nation's dependence on these institutions for its scientific education, and research and development enterprises. This second report presents many of these necessary, subsequent measures. Chiefly, these additional analyses are more qualitative in the nature of their objectives and conclusions. They attempt to measure the caliber of the students and the educational productivities of the schools. What do science graduates from these colleges do, immediately following graduation and thereafter? What are their patterns of graduate school attendance? What are their career paths? What contributions do they make to American science? How essential are they to the supply of future teachers of science, at the primary, secondary and post-secondary levels? How well represented are they in the various scientific honorary societies and biographical publications?

These and related questions are the principal subjects of this chapter. First, the most recent data on key quantitative measures begun for the 1985 report are presented, with amplification of several points made in that publication. Following this, a second section of this first chapter presents the results of various new studies of student outcomes from the 50 liberal arts colleges.

Chapter I
Section A

Student Characteristics

The 1985 report on "Educating America's Scientists" assembled a variety of first-time, quantitative data on the role of scientifically-active liberal arts colleges in the training of American scientists at the undergraduate stage in the national science pipeline. Among other things, these data found that:

* The proportion of freshmen intending a major in the basic sciences at 48 selected, private liberal arts colleges was nearly double that at highly selective public and private research universities, and was four times higher than national norms.

* While this proportion had fallen dramatically at the national level over the last ten years, and declined substantially in all research university groups, it had fallen hardly at all at the colleges. Absolute numbers of prospective scientists had risen at these college, unlike at their university counterparts, and nationally.

* The proportion of all recent graduates from these 48 colleges earning a major in the sciences was 25%, half again that of a set of 20 top-rated public and private research universities[3]. Again, while this percentage had declined steadily at the universities over the past decade, it had not diminished whatsoever at the colleges.

* These 48 colleges therefore attracted a growing share of the shrinking prospective science student market, and produced an increasing share of the diminishing numbers of U.S. science baccalaureates, shares which had grown significantly more rapidly over the past decade at these colleges than at the best research universities.

* Women formed substantial proportions of both prospective science majors and science graduates at the 48 colleges.

This first section of Chapter I updates these quantitative data, and expands importantly on the issues of absolute volume of baccalaureate degree production, and of women's presence in undergraduate science, based on additional data obtained from the United States Department of Education since publication of the 1985 report. The principal findings from this year's study are :

HIGHLIGHTS :

* The proportion of freshmen enrolled in the 50 colleges of the liberal arts and sciences intending a major in the sciences rose slightly in 1985 to nearly 30%.

* There appears some shift in the various disciplines of prospective interest. The largest growth appears in the "Other Sciences"[4] category, with biology continuing to exhibit a slow decline in absolute and proportional freshman interest.

* These data continue to stand distinctly in contrast to national trends, both at all institutions, and at the most selective public and private research universities.

* The estimated number of freshman prospective science majors enrolled at these 50 colleges rose substantially in 1985 over 1984 (up 13%, from 6,362 to 7,174). However, this overall finding is the result of increase reported in Other Sciences.

* The proportion of the most recent year's graduates from the 50 colleges having earned majors in the sciences also rose to slightly more than one in four.

* The absolute number of baccalaureates in all sciences rose 7% from the 1983 level, likewise chiefly due to increase in Other Sciences. Degrees in the traditional basic sciences remained practically constant.

* Women continue to represent substantial, and growing, proportions of both prospective freshman science majors (45%) and of graduates (43%) at these colleges. This later percentage is well above the value for the 20 top-rated research universities.

* Absolute numbers of baccalaureate degrees in the biological and physical sciences and mathematics, as reported to the U.S. Department of Education, awarded by the 50 liberal arts colleges are on the order of the absolute degree production in these fields by the 20 top-rated research universities.

* As a first-order measure of student quality in the sciences, SAT means, both mathematical and verbal, of prospective science majors at the 50 liberal arts colleges are substantially above national norms. However, insufficient data were obtained to perform key longitudinal analyses, and comparable data for the universities could not be obtained.

DETAILS :

Prospective Freshman Majors

As in 1985, each of the 50 liberal arts colleges was requested this year to supply the number of freshmen most recently enrolled intending to major in a science. Fourty-nine of the 50 institutions supplied such data. These results are summarized in Table I-1.

The proportion of freshmen enrolled in September, 1985, in the 50 liberal arts colleges expressing intention to major in the sciences appears to have risen slightly from its 1984 level. In that year, this figure was 27.8%. Based on data received this year, the 1985 value is 29.1%. This slight increase is perhaps best interpreted as maintenance of previous conditions rather than an upward trend.

Even maintenance should be considered highly significant, however, given continued downward trends nationally. The following table repeats one from the 1985 report (Chapter 1, Table VI, p. 24), and adds the most recent year's data (1985) concerning freshman intention to major in the sciences[5]:

Year of Enrollment	50 Colleges		Private Univs. High Selectvty		Private, 4-Year Non-Sectarian Colleges, High & V-High Selct		Nation	
	N	%	N	%	N	%	N	%
1975	- -	- -	7,603	26.3%	10,648	20.9%	174,721	9.9%
1976	7,002	31.8%	6,852	26.4%	10,791	20.8%	176,406	9.9%
1979	6,781	29.6%	4,794	17.7%	7,269	15.1%	116,396	6.8%
1984	6,362	27.8%	5,157	17.4%	6,603	14.0%	108,499	6.6%
1985	7,174	29.2%	4,685	15.0%	6,967	13.3%	83,014	5.0%

All three of the reference groups above have continued to show decline in the proportion of first-time, full-time freshmen indicating prospective interest in the basic sciences. Most also appear to have experienced continued erosion in absolute numbers of such freshmen. At the 50 liberal arts colleges, however, both numbers and the proportion are up.

This increase at these colleges results almost exclusively from growth in the numbers of freshmen indicating one of the "Other Sciences"[3] as the prospective major. Other disciplines show slight increase or decrease, save biology, which continued in 1985 to exhibit a slow but steady decline in both numbers and proportion. This trend now appears to be long-standing, and is cumulatively substantial (from 3,001, 13.6%, in 1976 to 2,089, 8.8%, in 1985). It is a good candidate for further study.

Baccalaureates in Science

Degree production in the sciences was also up at the 50 liberal arts colleges, both proportionately and in absolute numbers. In 1983, these colleges conferred an estimated 5,150 baccalaureates in all science disciplines, 23.7% of their total bachelors degree production. Based on the latest data received this year (all 50 schools reporting), absolute numbers conferred in 1985 have grown 3% to 5,310, 25.5% of the total baccalaureate volume (Table I-2). Reference data for national and university production are currently unavailable beyond 1983.

Absolute Numbers of
Baccalaureates in Science

Our studies have relied heavily on proportional methods to compare and contrast various key measures of undergraduate science at the 50 liberal arts colleges to national norms and to those at other reference groups of post-secondary institutions, particularly to a set of 20 leading research universities. This is required in order to correct for large differences in scale in the absolute numbers involved in these comparisons. While such correction is often methodologically necessary, it can divert attention from important comparisons of absolute numbers:

** A most significant point, bearing reiteration, and for which supplemental data have been obtained since the 1985 report, is the approximate equivalency between the 50 liberal arts colleges and the 20 top-rated research universities in absolute volume of undergraduate degree production in the sciences.

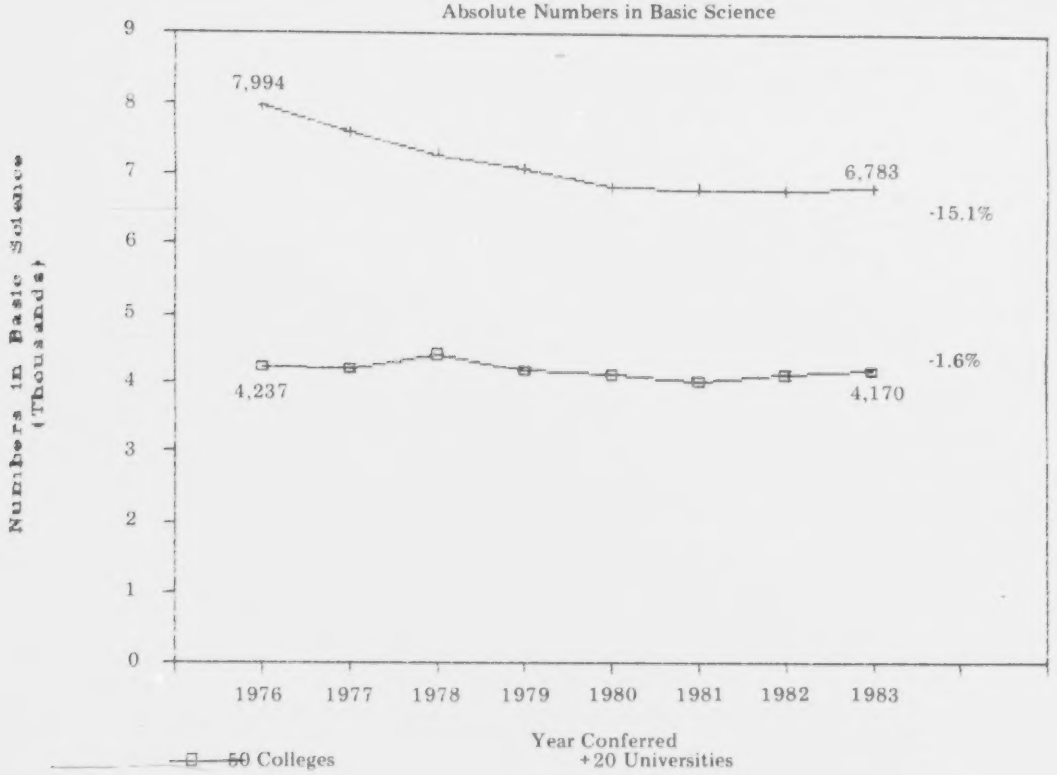
In order to examine accurately and completely the issue of volume of recent baccalaureate degree production in the basic sciences by these two groups of institutions, data reported annually to the U.S. Department of Education[6] were studied for the years 1976 through 1983. For this study all and only the majors designated by NCES as "biological sciences", "physical sciences" and "mathematics" were included. The absolute numbers of bachelors degrees in these majors conferred by the 50 colleges and the 20 universities over these eight years are plotted on the top graph, following page. The lower graph indicates the proportion of total baccalaureate volume in each of these years represented by B.A.'s in basic science.

Although the total volume of baccalaureate degree production in the basic sciences by the 50 liberal arts colleges is less than that of the universities, it is on the same order of magnitude. In 1983, the 20 universities conferred 6,783 bachelors in basic sciences; the 50 colleges produced 4,170. These data also indicate the changes in these absolute numbers from 1976 to 1983. As has been noted in these reports, the numbers conferred by the universities have fallen considerably over the decade (-15%, from 7,994) while those of the colleges have remained essentially constant (-2%, from 4,273).

In proportional terms, examining only degrees conferred in these majors (lower graph), these data confirm the higher per capita production in basic science at the 50 colleges, and the significantly smaller reduction in this proportion at these colleges over this period (-8%, from 20.5% to 18.9%) than at the universities (-19%, from 16.1% to 13.1%).

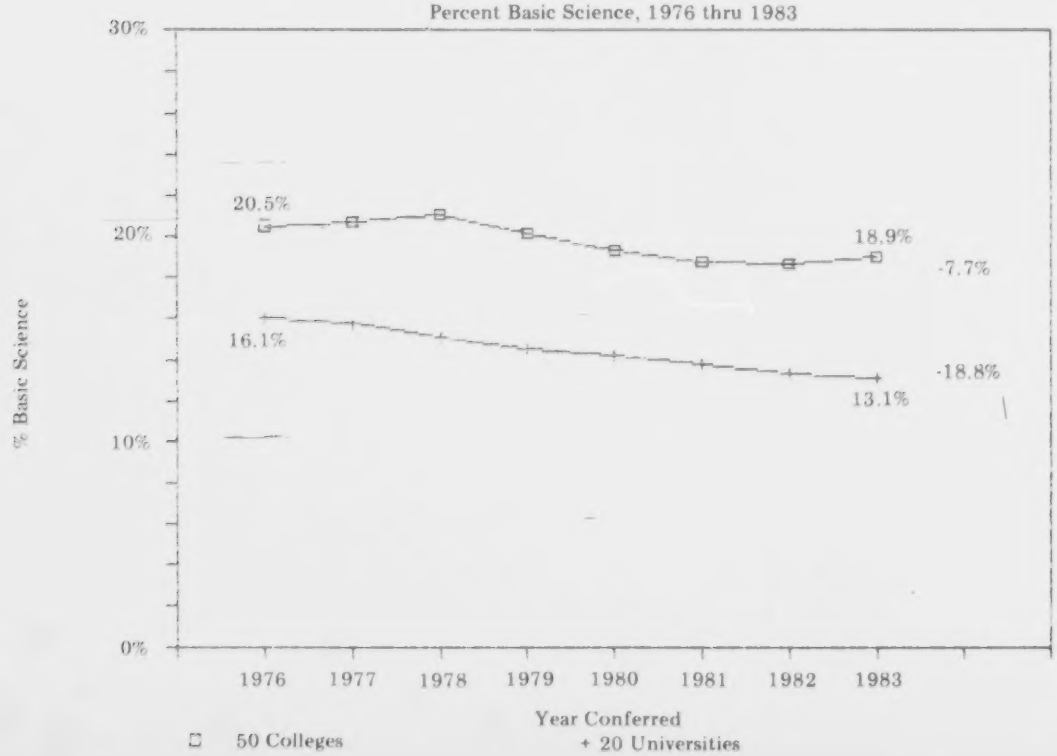
Baccalaureate Degree Production

Absolute Numbers in Basic Science



Baccalaureate Degree Production

Percent Basic Science, 1976 thru 1983



Women in Undergraduate Science

Over the next decade and beyond, the declining demography of the so-called "baby bust" is projected to reduce significantly the number of science and engineering (S/E) students entering, and eventually exiting from, America's science pipeline. One method to off-set the impact of the projected demographic reduction in American S/E personnel is to attract into scientific careers various groups traditionally underrepresented in the sciences. The most obvious of these are women and most ethnic minorities. As the following data[6] indicate, the 50 liberal arts colleges are a particularly rich and promising source of women scientists. (Preliminary data on minority students follow.)

The next page of graphs summarizes the relevant data visually. The top graph indicates the percentage of women graduated from the 50 colleges and the 20 universities having earned baccalaureate degrees in the sciences.

* The percentage of women majoring in the sciences at the 50 liberal arts colleges, 15.2%, is approximately half again that at the 20 top-rated universities, 11.1% (as is true comparing all graduates of these two sets of institutions.)

However, this proportion does appear to have declined slightly more from 1976 to 1983 at the colleges (-5.5%, 16.1% to 15.2%) than at the universities (-2.9%, 11.5% to 11.1%).

The lower graph examines women's presence in undergraduate science at these two groups of institutions from a different perspective. Again counting only majors in the basic sciences (NCES categories as before) :

* women are a rapidly rising percentage of all baccalaureate degrees conferred in the sciences at both the 50 colleges and 20 universities,

* with the colleges granting a higher percentage of their science B.A.'s to women, 43% (1983), than the university group (37%).

Over the period of 1976 through 1982, this college-university gap has been almost perfectly preserved. Although it narrowed somewhat in 1983, the last year for which these NCES data are currently available, it remains to be seen if this one year fluctuation represents a trend. Table I-2 suggests that such a trend likely does not exist, however, and indicates conclusively that women's presence among science majors from the 50 liberal arts colleges has continued to rise, to nearly half (46%) of all graduates in the basic sciences in 1985.

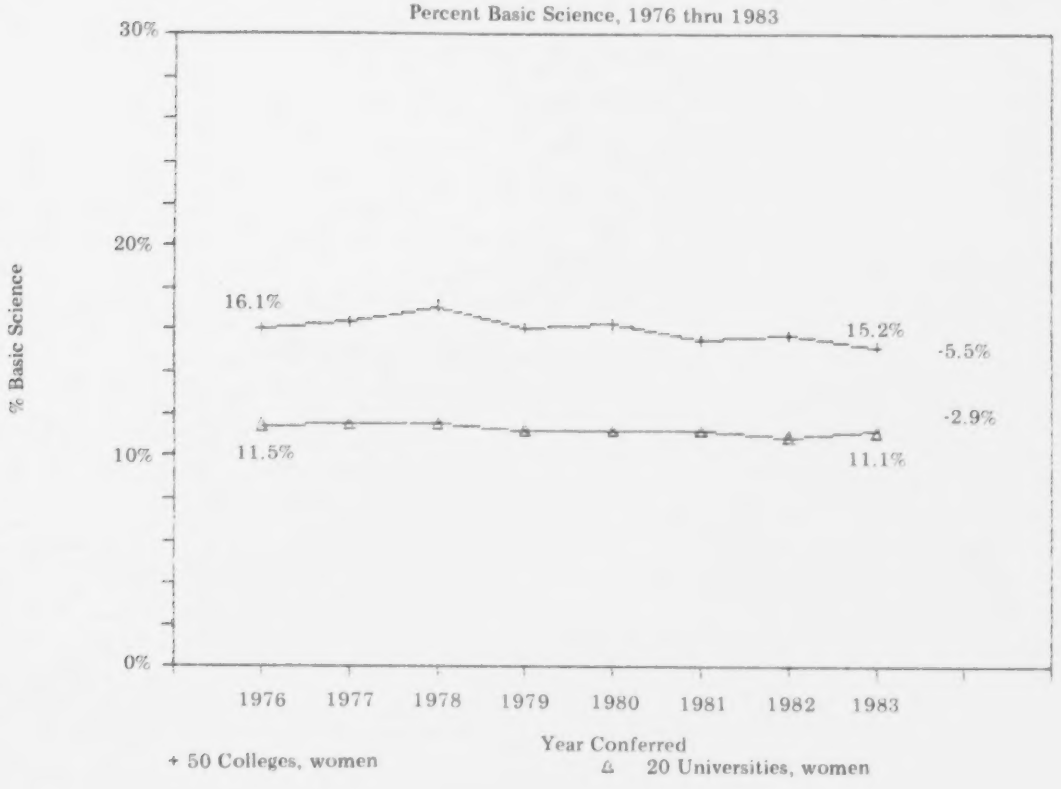
Minorities in Science

Table I-1 also presents the numbers of ethnic minority students enrolled as freshmen in the fall of 1985 at the 50 liberal arts colleges intending to major in a science. These numbers are also expressed as percentages of the total numbers of prospective majors in each of the scientific (and non-science) disciplines.

In total, 9.0% of all new freshmen at these colleges were members of ethnic minority groups. In all sciences, this figure was 12.3%; 11.3% excluding the Other Sciences category. The highest proportions appear in the Other Sciences (13.7% minority), Chemistry (13.3%) and Biology (13.1%). The remaining disciplines ranged from 5.9% to 8.0%.

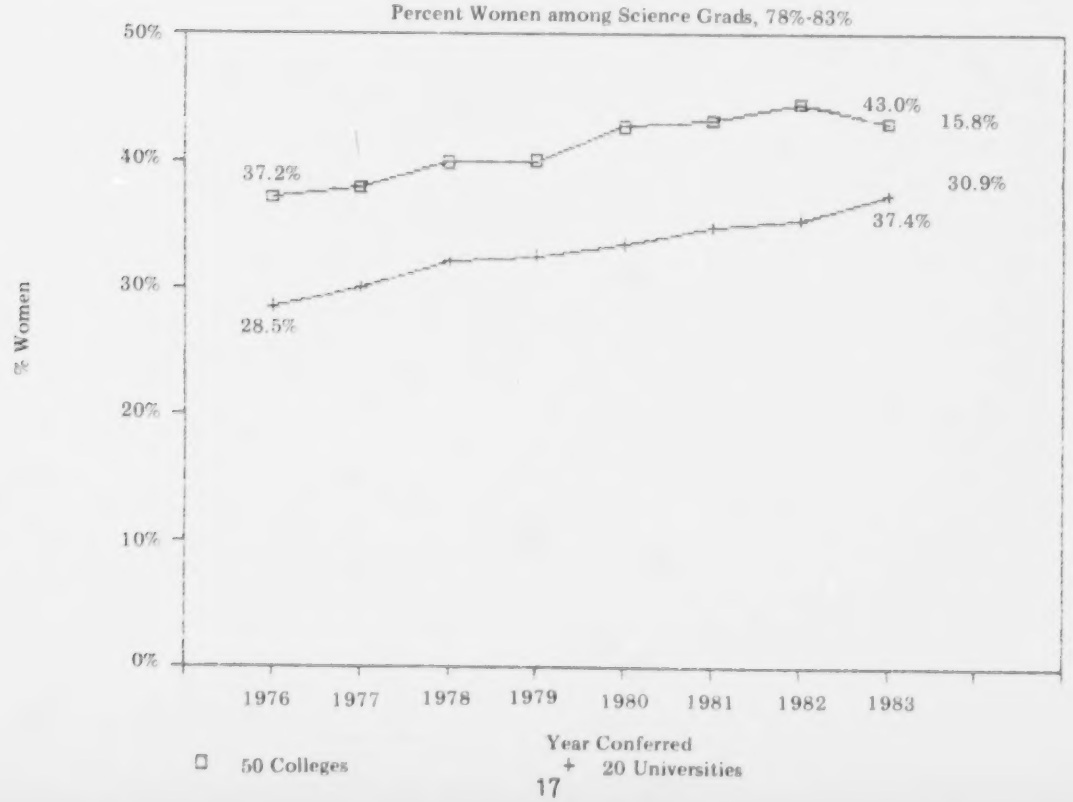
Baccalaureate Degree Production, Women

Percent Basic Science, 1976 thru 1983



Baccalaureate Degree Production

Percent Women among Science Grads, 78%-83%



Examined differently, fully 853, or 39.8% of the minority students enrolled at these colleges as freshmen intend to major in a science. Excluding prospective majors in Other Sciences, this figure remains high (21.3%). The respective proportions for majority students are lower: 28.1% and 16.6%.

This is the first year these data have been available. Given the general stability of the enrollments at these institutions, however, they suggest that these colleges are successful in attracting a reasonably large proportion of minority students, higher percentages of whom are initially interested in the sciences than is the case for majority students. More data are required to confirm this suggestion, and to search for trends in patterns of freshman minority enrollments. Also, the more important data on degree production by ethnic background were not available from a sufficient number of institutions to draw confident conclusions. More data and analysis are required, probably employing NCES data, and providing comparative analyses with national norms and those of other key reference groups. These should be available in subsequent studies.

SAT Score Means

These quantitative data must now begin to be supplemented with a variety of more qualitative measures. A second section of this chapter will examine a number of educational outcomes measures as indicators of the level of scientific aptitude in the students at the liberal arts colleges, and of the quality of their scientific training there. As one first-order input measure of the quality of science student at these colleges, data were collected by discipline on the SAT score means of the prospective science majors enrolled in September, 1985 (i.e., the students whose numbers are presented in Table I-2.)

These results are summarized in Table I-3. The only comparative data obtainable are national norms in three general disciplinary areas[7]:

Prospective	Mathematical		Verbal	
Major area	50 Cols	Nation	50 Cols	Nation
Biology	605	516	570	480
Physical Sciences	643	569	581	506
Mathematics	651	578	567	451

Clearly, both the mathematical and verbal aptitude means of prospective science students at these colleges are well above national norms. (Data for university norms by discipline proved unobtainable in reliable form.)

National SAT means began to decline in the early 1960's and continued to do so until the last two or three years. These declines, and shifts in the patterns of choice of prospective majors, affected both the national mathematical and verbal SAT averages of students intending science majors[8]. It was hoped that a longitudinal analysis of SAT means by prospective science discipline could be performed for the 50 colleges to determine if the quality of these colleges' science students had been maintained as well as their proportion and quantity. However, these data proved impossible to retrieve. Only five of the 50 colleges provided historical SAT data, too small a sample from which to draw conclusions.

Chapter I
Section B

Student Educational Outcomes

"In June, the presidents of 48 liberal arts colleges met to call attention to the superiority of their institutions for the education of scientists. ... Statistics gathered in their report show that the 48 colleges have outstanding records in encouraging students to complete bachelor's degrees in the sciences and to carry on to Ph.D.'s. The liberal arts colleges surpass in these respects the 20 research universities whose graduate programs were highest rated ... The data in these reports demonstrate that a single linear ranking of colleges and universities will not suffice. Those that are excellent for graduate education turn out to be less excellent for undergraduate education. ... A note of qualification: the data show that liberal arts colleges excell in inspiring or encouraging students to study for science degrees; they allow the possibility that the research universities offer superior instruction to the student who is firmly dedicated to science from the outset."

J.F. Bunnett
"The Origins of American Scientists",
in Accounts of Chemical Research,
Vol. 18, No. 8, August, 1985

The generally quantitative data from the 1985 report and this one make a strong case for the essential role of the liberal arts colleges in the maintenance of a vigorous, creative and competitive scientific enterprise in America. However, it is also essential to demonstrate that the scientists trained at liberal arts colleges are of a quality, and make contributions to science, in proportion to their quantity (as Dr. Bunnett, and others, have noted). The studies presented in this section begin this demonstration. This is accomplished primarily by examining a wide variety of eventual student outcomes in science, comparing their values for the 50 liberal arts colleges to those of the 20 top-rated research universities adjusted for undergraduate size. On these more qualitative measures as well, the liberal arts colleges are unfailingly found to be ranked equally with the best unversities at the undergraduate level.

HIGHLIGHTS :

- High proportions of recent science graduates from the 50 liberal arts colleges enroll within five years following receipt of the baccalaureate in graduate programs leading to advanced degrees in science.

- While this percentage varies somewhat by discipline, it appears that 25% to 33% of all science graduates of these colleges enroll in graduate degree programs in science within five years. Another 28% to 38% enroll in professional degree programs related to their undergraduate work (e.g., M.D., engineering, etc.)

- The most recently graduated class of scientists from the 50 colleges (1985) appears to be continuing these normative patterns.

- The 50 liberal arts colleges appear prominently among the most productive institutions per capita on six measures of student outcome: receipt of NSF Fellowships, earned doctorates in the sciences, membership in American Men and Women of Science, listing in Who's Who in Frontier Science and Technology, appearance among the 1,000 authors of scientific literature whose work is most often cited in subsequent publications, and membership in the National Academy of Sciences.

- When ranked with the 20 top-rated research universities, the colleges command a majority of the 25 most productive institutions per capita on fully five of the six outcomes measures. The colleges form a majority of the ten most productive schools on two of the measures, and represent exactly five of the top ten institutions in per capita productivity on two other measures.

- Six of the 50 colleges are ranked among the ten most productive institutions, colleges and universities, of (post-war) undergraduate alumni having earned membership in the National Academy of Sciences. Other than receipt of the Nobel Prize, election to membership in the National Academy is generally considered the most prestigious and selective recognition having representation from all disciplines.

- When all 50 of the liberal arts colleges are compared in aggregate to all 20 of the top-rated universities on these six outcome measures, the universities tend to hold a modest edge over the colleges. However, the data clearly place student outcomes in science per capita from these colleges on the same order as that of the best U.S. research universities.

- Data could not be obtained in time for this report on longitudinal GRE scores, and the undergraduate origins of science faculty at premier research universities. The results of these studies should be available for subsequent reports.

DETAILS :

Graduate School Attendance

Education beyond the bachelor's level is required to make a meaningful contribution to scientific knowledge. Typically this means a doctorate, but can mean other degrees in fields such as engineering, computer science, and, in some cases, medicine. Therefore, the frequency with which science graduates from the liberal arts colleges enroll in graduate programs for degrees in the sciences and related areas is of great importance. While this measure alone is not a demonstration of quality or contribution, it is sine qua non to these. If patterns of graduate school attendance were low, it could be fairly assumed that quality and contribution were also.

Tables I-4 through I-8 present information on the numbers and percentages of the graduates from the 50 colleges in the classes of 1980 and 1985 having enrolled in various graduate school options. The proportions are generally high. Tables I-4 and I-5 indicate the numbers of graduates, by discipline and in total, from the class graduated in 1980 having enrolled immediately (I-4) and to date (I-5) in graduate school. (The numbers are estimated totals for the full set of 50 colleges based on the 22 schools having reported these data.)

These data find a fairly consistent pattern of attendance in the first year following graduation: approximately 20% to 25% enrolled immediately in graduate programs leading to advanced degrees in science. Another 20% to 30% enrolled in professional degree programs (typically the M.D. or engineering degrees). Only 25% to 35% were known not to have attended graduate school immediately. The primary exceptions in this class from the institutions reporting appear to be graduates in geology and mathematics, of which slightly more than half (55%) were known not to have enrolled in graduate programs immediately following receipt of the baccalaureate.

Given a longer period of time (five years following receipt of the bachelors), substantially higher proportions appear to go on to advanced degrees (Table I-5). In all disciplines, and discounting the 25% for which outcomes to date are not known, one third (33.7%) have enrolled in graduate programs in the sciences per se. Another 37.5% have elected related professional degree programs. Only a very low proportion, one in five (20%), has not enrolled in advanced education. By this time, the percentage of geology graduates having enrolled in advanced degree programs in science is the highest of all disciplines (67.2%). Mathematics graduates, however, remain those with the highest proportion not enrolled in graduate-level programs (36%).

These data are somewhat problematic, however. In addition to the relatively low number of the 50 colleges reporting these data (22 in each table), the particular 22 institutions having provided the immediate outcomes are a slightly different set than those reporting outcomes to date. For this reason, estimated total numbers of science graduates differ between these two tables, and only the proportions having enrolled in the various graduate school options should be compared between Tables I-4 and I-5.

The standard method for handling such incongruity in two sets of data is to restrict the analysis to all and only those institutions common to both sets, in this case, those colleges providing both one-year and five-year patterns of graduate school attendance. This analysis is presented in Tables I-6 and I-7 (respectively the immediate attendance patterns and those to date). While this restriction makes the one-year and five-year patterns more properly comparable, it additionally reduces the number of institutions on which analysis can be based (from 22 to 14).

Even so, it is notable that the proportions of science graduates from these colleges having enrolled in the various graduate school options are not substantively different than those found using the mixed sets of 22 institutions. This convergent result provides important additional confidence in these findings. However, more comprehensive data are necessary to derive the patterns of graduate school attendance of science graduates from the 50 liberal arts colleges with high confidence. Nevertheless, it does appear all but certain that high proportions of the science graduates from these 50 colleges pursue advanced degrees both in the sciences and in related professional areas.

Finally, Table I-8 presents the data on the one-year patterns of graduate school attendance for the most recently graduated class (1985). Thirty-three of the 50 colleges provided such data and are represented in this table. Therefore, again, these data are not perfectly commensurate with those in the previous four tables. Nevertheless, reasonably similar one-year attendance patterns are found for this class as were found for the class graduated in 1980. This consistency too lends additional confidence to these results, especially given the relatively large number of institutions reporting in Table I-8.

Qualitative Educational Outcomes Measures

Measuring contribution to the advancement of scientific knowledge is not a simple matter. No standardized or universally recognized vehicle exists for doing so. Nevertheless, a variety of substantive and honorary outcomes are readily measured and would generally be agreed to provide at least first-order tests for contribution to the scientific enterprise.

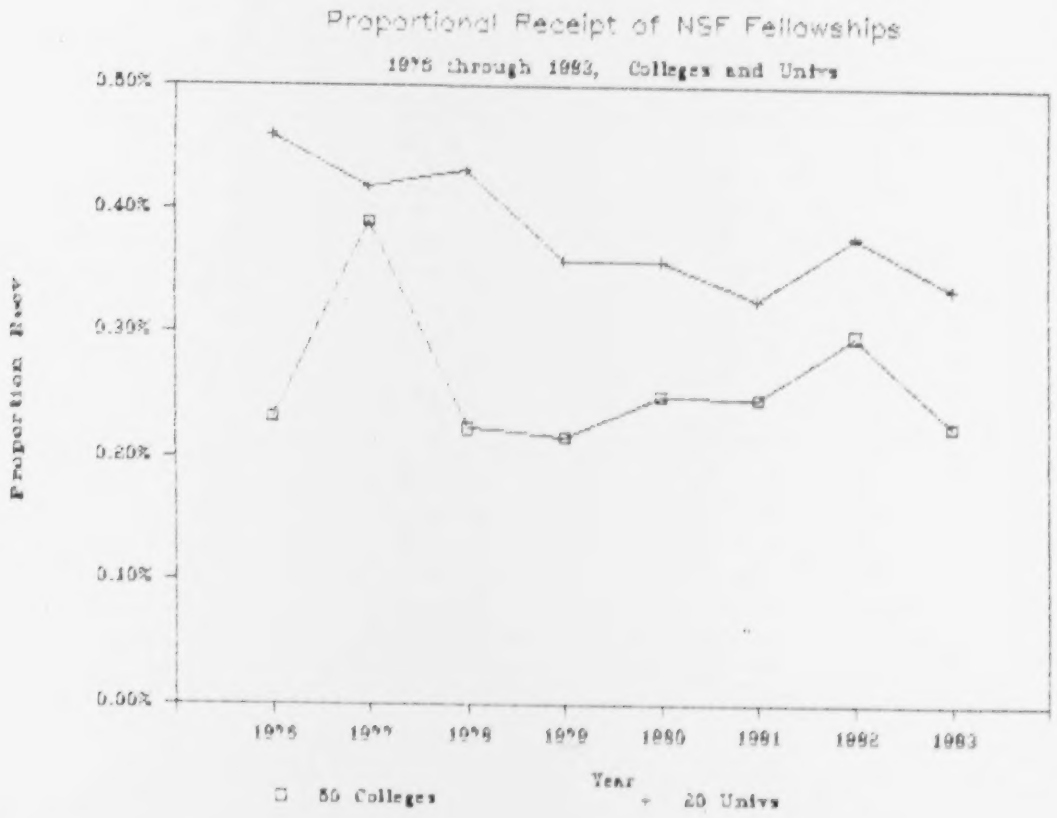
In this section, we present six distinct such outcomes studies, each measuring a different attainment in science. Each examines the percentage of an institution's graduates, or a set of institutions' graduates, over some period of time having earned a well-recognized achievement in science. Importantly, all six measures indicate highly consistent results. These data are presented in Tables I-9 and I-10.

N.S.F. Fellowships

The first outcome measure is one typically occurring very soon, often immediately, following receipt of the baccalaureate. Each year, the National Science Foundation awards a small number of fellowships to first-year students pursuing graduate study in the sciences[9]. Approximately 450 to 500 of these fellowships are awarded each year through a highly competitive selection process. They are given only to students having demonstrated both substantial achievement at the undergraduate level and significant promise for advanced study. These awards are published each year, indicating the undergraduate

institutions of the NSF fellows.[10] These awards were tallied for each of the 50 colleges and the 20 universities[6] in each of the eight years from 1976 through 1983 (inclusive). The NCES data (see p. 13) on total numbers of baccalaureate degrees conferred by each of the colleges and universities in each of these years were used to adjust NSF Fellowship volume for undergraduate size. This methodology thus computes the proportions of the graduates of these institutions having been awarded NSF fellowships. These percentages are presented for the 25 most productive of these colleges and universities in Table I-9, with the raw data for each group in each year detailed in Table I-10.

Four of the 50 liberal arts colleges are found among the ten colleges and universities having the highest per capita productivity of students awarded recent NSF fellowships. In the top 20 such institutions, the colleges number 11. A majority (14) of the 25 most proportionately productive schools of recent NSF fellows are primarily undergraduate colleges. Examining all 50 colleges and all 20 universities as groups, 0.26% of the colleges' graduates over this eight period have earned these fellowships, as compared to 0.38% for the universities. For those 14 colleges and 11 universities found among the 25 most productive of NSF Fellowship recipients, the percentages are 0.80% and 0.95% respectively. The graph below plots the percentages of all bachelors graduates from the 50 liberal arts colleges and 20 top-rated universities receiving NSF fellowships in each of the eight years from 1976 through 1983 (data source, see Table I-10).



Earned Doctorates in the Sciences

The second educational outcome measure is the proportion of all graduates between the years 1946 and 1976 having earned doctorates in the sciences[11] between the years 1951 and 1980. These data are taken directly from a comprehensive study of the 350 (approx.) colleges and universities most proportionately productive of doctorates in all fields published by Carol Fuller[12]. These data (restricted to the 50 liberal arts colleges and 20 top-rated universities), again are presented individually for the 25 most productive institutions, and for the two groups in aggregate, respectively in Tables I-9 and I-10.

Once again, the colleges are prominently ranked, comprising 5, 12 and 15 respectively of the 10, 20 and 25 most proportionately productive institutions of undergraduates earning doctorates in the sciences. Also similar to the NSF fellowship results, the 50 colleges' aggregate productivity of science Ph.D.'s (3.21%) is only slightly below that of the universities (3.99%). Among only those 15 colleges and 10 universities ranking among the 25 most productive, these proportions are 5.96% (colleges) and 7.61% (universities).

Membership in American Men and Women of Science and Who's Who in Frontier Science and Technology

The next two outcomes measures are successively more restrictive beyond earning the doctorate. These are membership in American Men and Women of Science, and membership in Who's Who in Frontier Science and Technology. A.M.W.S. membership demands both the demonstration of the ability to do independent research, as evidenced by an earned doctorate, and the publication of the results of at least one substantive research project beyond the doctoral thesis. Membership in A.M.W.S. totals approximately 126,000, or slightly less than one-third of all living science and engineering doctorates.

Membership in Who's Who in Frontier Science and Technology is by nomination and a subsequent screening process only. It is much more restrictive, totaling only 5,648 (as of 1986), approximately 1.5% of all S/E doctorates. As its name implies, these are scientists judged to be performing significant research which is on the cutting edge of their disciplines.

Tables I-9 and I-10 present the proportions of the post-war alumni[13] of the 50 liberal arts colleges, and those of the 20 universities, currently holding membership in A.M.W.S. and in this special sub-group of Who's Who in America. Once again, the 50 colleges are prominently represented in the 25 institutions most productive of undergraduate alumni holding these distinctions.

This is particularly so for A.M.W.S. membership. On this measure, seven of the top ten institutions are colleges, with two of the three universities being primarily technically oriented (the California Institute of Technology, and the Massachusetts Institute of Technology). Colleges comprise 15 of the top 20, and 17 of the top 25, thus dominating the institutions most productive of post-war undergraduates earning membership in A.M.W.S. On this measure, the 50 colleges in aggregate are essentially equal in proportional productivity to these 20 universities. Overall, 1.32% of all the post-war alumni of the colleges currently hold membership in A.M.W.S. For the universities, this proportion is 1.33%.

The more highly refined measure of Who's Who membership finds somewhat fewer colleges. Nevertheless, the colleges are essentially half (11) of the 25 most productive institutions on a per capita basis of alumni holding this distinction. These 11 colleges have an aggregate proportional productivity of 0.44% on this measure, only slightly below the aggregate figure for the 14 most productive universities (0.55%).

Science Citation Index :
The 1,000 Most-Cited Authors

Scientific knowledge is principally recorded and transmitted through the written media. Publications in numerous scientific journals and books are the primary method of reporting the findings from new research, and of interpreting and integrating research findings into broader knowledge and understanding. Scientific literature also performs the equally important functions of cementing and removing such findings from the body of scientific knowledge, through confirmation or denial by independent investigators, and of expanding major findings into all their ramifications. Publication thus forms the official record of scientific progress: who, what and when.

It is in the nature of scientific progress that almost all new findings grow out of the large, pre-established body of knowledge. In turn, each result typically raises the next series of questions to be answered by subsequent research. Because of this almost exclusively chain-like nature in science, authors reporting the results of their research in the scientific literature must cite the earlier work of other investigators into order to place new findings into their proper context. The principal findings and major breakthroughs in science give rise the the most rapid and voluminous subsequent research. Therefore, the number of times a particular publication is cited in subsequent ones is one, first-order measure of the importance and contribution of the earlier-reported work. This simple argument is clearly not without certain important qualifications and limitations. Nevertheless, careful and extensive records are maintained of the citation of scientific publications, and a great deal of study has been devoted to the authors and patterns found in the citation of scientific literature.

One of the major such studies was an accounting of the 1,000 most often cited authors of scientific literature published from 1965 - 1978[14]. For this study of undergraduate science and liberal arts colleges, we have compiled the undergraduate origins of these authors[15], tallied these origins for each of the 50 colleges and 20 premier research universities, and divided these raw counts by the undergraduate sizes of each institution. These percentages, also reported in Tables I-9 and I-10, thus form another measure of student outcome in science for these colleges and universities. They are a first-order measure of per capita productivity of scientists performing the most important work in their fields.

In this analysis of the Science Citation Index data, the 50 colleges are again very well represented among the most productive institutions, even when ranked with the best research universities. One of the colleges (Swarthmore) leads this ranking. Colleges form fully half of the ten most productive institutions, and are a majority of both the top 20 and top 25 such schools, numbering 12 and 15 respectively. These 15 most-productive colleges have an aggregate productivity ratio of 0.040%, practically equal to the aggregate ratio for the 10 most productive universities (0.043%). This ratio for all 50

colleges is 0.012%, somewhat below the ratio for all 20 universities (0.020%), as appears to be typically the case with these student outcomes measures analyzing proportional productivities for these institutions.

National Academy of Sciences Membership

In all likelihood, the most prestigious and selective award in science other than the Nobel Prize with representation of all disciplines is election to the National Academy of Sciences. Here again, although absolute numbers and proportions from all institutions are small, members of the 50 liberal arts colleges are found to be very prominent *per capita* producers of scientists eventually earning this most distinguished honor[16]. A majority (6) of the ten most productive institutions are colleges. The colleges number 10 of the top 20, and fully 15 of the top 25. In aggregate, 0.015% of the post-war alumni[17] of the 50 colleges currently hold membership in the National Academy. The proportion for the universities is 0.031%. Limiting analysis to only the 15 colleges and the 10 universities ranked among the 25 most productive *per capita*, 0.046% of the colleges' alumni, and 0.70% of the universities' graduates, hold membership in the National Academy of Sciences.

Summary

These analyses provide a good preliminary picture of student educational outcomes in science from the 50 liberal arts colleges. They are sufficiently consistent to suggest strongly that these colleges attract and educate scientists on a par with the best American research universities at the undergraduate level. These data, in conjunction with the quantitative measures, particularly those of absolute and proportional baccalaureate science degree production, strongly reinforce the contention that the liberal arts colleges are among the most productive centers of high quality education in the sciences, and represent resources the nation cannot afford now to allow to diminish in size or quality.

End Notes -- Chapter I
Student Characteristics and Educational Outcomes

[1] Davis-Van Atta, D., Carrier, S., Frankfort, F., "Educating America's Scientists: The Role of the Research Colleges", Oberlin College, 1985.

[2] In the 1985 report (Ibid., note 1 above), 48 colleges were represented in the data collection and at the presidential conference. However, a total of 50 colleges met the formal criteria for for inclusion in the study. Two (Hamilton College, NY, and Occidental College, Ca.) for various reasons could not participate in 1985. These two institutions were able to participate in the 1986 study and their data are thus represented in this report. Therefore, this report will refer to the full set of 50 liberal arts colleges throughout.

[3] A list of these universities, and reference to the source of their rating, is found in the 1985 report (Ibid., note 1 above), p. 101.

[4] Throughout this report, as in that of 1985, "Other Sciences" contains data on computer sciences (for institutions where it is a separate department from mathematics), some engineering, environmental sciences, bio-psychology, etc. Psychology per se is not included in this study.

[5] Data source: Astin, A., Green, K., Korn, W., Schalit, M., The American Freshman: National Norms for Fall 1985, Cooperative Institutional Research Program, Graduate School of Education, University of California at Los Angeles, Los Angeles, California, 1985. For this data source, "sciences" is used to mean the sum of all "biological sciences" plus all "physical sciences".

[6] Unpublished data from the United States Department of Education, National Center for Education Statistics, as reported to DOE through its annual Higher Education Information General Survey (HEGIS) instrument, "Degrees and Other Formal Awards Conferred".

[7] College-Bound Seniors, 1985, The College Board, New York, New York, 1985.

[8] See the 1985 report (Ibid., note 1 above), Chapter 1, Table IV, p. 21.

[9] NSF Fellowships include some awards made to students intending graduate study in several social sciences.

[10] This analysis, and the other five proportional outcomes measures presented in this report, examine only the 50 colleges and the 20 top-rated universities. No other institutions' data are included. Comprehensive analysis is currently being contemplated, but represents a substantially larger study. It is reasonable to believe that the more limited analyses presented here are likely accurate proxies for comprehensive studies. In any event, the data presented here do provide accurate comparisons of student outcomes for the 50 selected colleges and the 20 selected universities.

[11] The data on doctoral production are those from the standard source, The National Research Council of the National Academy of Sciences. Therefore they follow NRC definitions of science fields. The data representing science fields in this report are those termed "Life Sciences" and "Empirical Sciences" by the NRC. The Life Sciences consist of biochemistry, basic medical sciences, other bio-sciences, medical sciences and agricultural sciences. The Empirical Sciences include physics, astronomy, chemistry, earth sciences, mathematics, chemical engineering and engineering. Clearly, these data unavoidably examine Ph.D. production in a number of disciplines not typically offered at liberal arts colleges, but more often found, even at the undergraduate level, in research universities. Therefore, if these data could be restricted to doctorates earned in the traditional basic sciences, it is almost certain that the 50 colleges' proportions of graduates earning such doctorates would be even higher than indicated in this report.

[12] Fuller, C., An Analysis of Leading Undergraduate Sources of Ph.D.'s, Adjusted for Institutional Size, The Great Lakes Colleges Association, Ann Arbor, Michigan, August, 1986.

[13] The denominators of the percentages for A.M.W.S. membership and for Who's Who membership, as well as those for Ph.D. production and the Citation Index analysis, are those computed and reported in the Fuller study of proportional Ph.D. productivity (1986, endnote 12 above). As such, it should be noted that these data have been corrected for the presence of first-professional degrees, a methodological problem in the first edition (1985) of the Fuller data which artifactually lowered productivity ratios, and differentially so to the distinct disadvantage of universities. The more recent data, used for this report, have substantially corrected this problem.

[14] Garfield, E., "The 1,000 Contemporary Scientists Most-Cited 1965-1978. Part I. The Basic List and Introduction", in Current Comments, (41):5-14, 12 October, 1981, pp. 269 - 278, Institute for Scientific Information, Philadelphia, Pa.

[15] The undergraduate origins of approximately 75% of these 1,000 authors proved easily retrievable (principally from publications of American Men and Women of Science). Most, although not all of those unidentified, appeared to be foreign citizens.

[16] Membership in the National Academy is counted in five "classes" into which members assign themselves only to one: physical sciences and mathematics, biological sciences, engineering and applied sciences, medical sciences, and social and behavioral sciences. Only members in the first four NAS Classes are included in this study (i.e., these analyses are exclusive of of social and behavioral sciences membership.)

[17] A technical correction to the C. Fuller post-war undergraduate degree numbers must be made in order to compute proportional production of NAS members properly. The numerators of the NAS productivity percentages presented in this report include only the numbers of NAS members with undergraduate origins from the selected schools who earned the bachelors degree since 1945. This is so that selected data assembled by Ms. Fuller could be used in the denominators of these productivity ratios. However, verbatim use of the Fuller data would be at least somewhat inaccurate since the latest year of baccalaureate receipt by a current NAS member is 1969. For this reason, the proper denominators for this measure of proportional productivity must be total numbers of bachelors

degrees granted from 1945 through 1969, not those from 1946 through 1976 contained in the Fuller study. These proper data were assembled by one of us (Davis-Van Atta), also corrected for the presence of first-professional degrees, but are too voluminous to report in detail here. They may be obtained from the author.

As well, less than one-third of all living NAS members were granted their bachelor's degree after 1945. If reliable undergraduate degree production data could be assembled on an individual institution basis for the pre-war years, it would also be desirable to repeat the analysis here for all current members of the NAS, regardless of year of B.A. receipt.

Table I-1

Absolute and proportional freshman intention to major in science at the 50 liberal arts colleges, Fall 1985

Discipline	All Freshmen N	All Freshmen % of Total N	Women N	Women % Women	Minorities N	Minorities % Mnrty
Biology	2,089	8.8%	1,227	58.7%	274	13.1%
Chemistry	609	2.6%	210	34.5%	81	13.3%
Geology	92	.4%	40	43.1%	5	5.9%
Mathematics	794	3.3%	383	48.3%	64	8.0%
Physics & Astr.	472	2.0%	113	23.8%	32	6.9%
Basic science sub-total	4,056	17.0%	1,973	48.6%	457	11.3%
Other sciences (2)	2,896	12.1%	1,133	39.1%	396	13.7%
All science sub-total	6,952	29.1%	3,106	44.7%	853	12.3%
Non-sciences	13,353	55.9%	7,623	57.1%	1,047	7.8%
Undecided	3,565	14.9%	2,250	63.1%	242	6.8%
GRAND TOTAL	23,870	100.0%	12,979	54.4%	2,142	9.0%

(1) Data are estimates for the aggregate of all 50 colleges, based on a sample of 49 reporting.

(2) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) Minorities includes U.S. citizen black, Hispanic, Asian, American Indian, and all "other minorities."

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Table I-2

Absolute and proportional baccalaureate degree production in the sciences at the 50 liberal arts colleges, 1985

Discipline	All Graduates N	All Graduates % of Total N	Women N	Women % Women
Biology	1,687	8.0%	955	56.6%
Chemistry	765	3.6%	293	38.3%
Geology	357	1.7%	113	31.7%
Mathematics	755	3.6%	388	51.4%
Physics & Astr.	416	2.0%	83	20.0%
Basic science sub-total	3,980	18.8%	1,832	46.0%
Other sciences (2)	1,330	6.3%	416	31.3%
All science sub-total	5,310	25.1%	2,248	42.3%
Non-sciences	15,839	74.9%	9,469	59.8%
GRAND TOTAL	21,149	100.0%	11,717	55.4%

(1) Data are aggregate figures for all 50 colleges, based on a complete sample of 50 reporting.

(2) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

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Table I-3

Basic Academic Profile Data : freshman SAT Math and Verbal means and percentage in 1st decile of high school class, by intended major, for 27 of the 50 liberal arts colleges, Fall 1985

Intended Major	SAT Math Mean	SAT Math S.D. *	SAT Verbal Mean	SAT Verbal S.D. *	% in 1st Decile	1st Decile S.D. *
Biology	607.6	41.7	571.9	42.1	62.5%	21.2%
Chemistry	629.5	44.8	573.5	42.6	62.9%	22.7%
Geology	620.2	68.5	569.0	78.4	41.0%	37.0%
Mathematics	651.8	44.0	567.6	52.1	64.5%	20.7%
Physics & Astr.	664.0	52.8	598.7	56.6	62.1%	27.6%
Basic sciences	626.3	40.6	574.4	43.5	62.5%	19.2%
Other sciences (3)	600.0	40.5	546.4	50.0	53.2%	20.2%
All sciences	614.4	39.4	561.8	43.9	58.3%	19.1%
Non-sciences	581.5	48.7	580.9	52.3	48.0%	21.5%
Undecided	589.4	52.8	552.5	65.1	61.3%	24.2%
ALL FRESHMEN	592.7	41.8	571.0	49.7	53.1%	20.6%

(1) SAT means are weighted averages for a sample of 27 of the 50 institutions reporting data on SAT scores and numbers of prospective freshman majors.

(2) 1st. Decile percentages are weighted averages for a sample of 23 of the 50 institutions reporting data on class rank and numbers of prospective freshman majors.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

* S.D. = Standard deviation in SAT means and % 1st decile among the 27 institutions providing data (not among individual student scores).

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Table I-4

Patterns of graduate school attendance among science graduates
at the 50 liberal arts colleges

Class of 1980 : first year out (1980-81)

Discipline	Attend Graduate School: science N	science %*	professional	professional %*	non-science	non-science %*	No Grad. School **	No Grad. School %*	Outcome Unknown	Outcome Unknown %*
Biology	295	16.1% 21.0%	573	31.3% 40.8%	80	4.3% 5.7%	457	24.9% 32.5%	427	23.3%
Chemistry	239	27.3% 31.2%	266	30.5% 34.7%	25	2.9% 3.3%	236	27.1% 30.9%	107	12.2%
Geology	109	28.9% 37.2%	0	.0 .0	20	5.4% 7.0%	164	43.4% 55.8%	84	22.3%
Mathematics	84	14.4% 20.8%	45	7.8% 11.2%	50	8.6% 12.4%	225	38.5% 55.6%	180	30.7%
Physics & Astr.	123	34.6% 45.8%	41	11.5% 15.3%	20	5.8% 7.6%	84	23.7% 31.4%	86	24.4%
Basic sciences	850	21.1% 27.1%	925	23.0% 29.5%	195	4.9% 6.2%	1,166	29.0% 37.2%	884	22.0%
Other sciences (3)	111	10.9% 38.0%	70	6.9% 24.0%	9	.9% 3.1%	102	10.0% 34.9%	727	71.3%
All sciences	961	19.1% 28.0%	995	19.7% 29.0%	205	4.1% 6.0%	1,268	25.2% 37.0%	1,611	32.0%

(1) Data are estimates of the aggregate totals for all 50 colleges, based on a sample of 22 reporting.

(2) The sample of 22 reporting represents all available data, and INCLUDES patterns of graduate school attendance from seven institutions NOT providing similar data on the class of 1980 as of five years after degree receipt (see Table I-5).

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

* The first figure in the "%" columns for each discipline represents the unadjusted proportion of all graduates in that discipline with a given outcome. The second figure represents the adjusted proportion excluding graduates for whom outcome is unknown.

** Known not to have attended graduate school.

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Table I-5

Patterns of graduate school attendance among science graduates
at the 50 liberal arts colleges

Class of 1980 : outcomes to date (1985-86)

	Attend Graduate School									
	science		professional		non-science		No Grad. School **		Outcome Unknown	
Discipline	N	%*		%*		%*		%*		%*
Biology	345	20.5% 27.3%	595	35.3% 47.1%	105	6.2% 8.3%	218	12.9% 17.3%	425	25.2%
Chemistry	298	31.0% 36.1%	348	36.3% 42.1%	34	3.6% 4.1%	145	15.2% 17.6%	134	14.0%
Geology	186	55.0% 67.2%	11	3.4% 4.1%	20	6.0% 7.4%	59	17.4% 21.3%	61	18.1%
Mathematics	164	21.8% 33.5%	84	11.2% 17.2%	66	8.8% 13.5%	175	23.3% 35.8%	264	35.0%
Physics & Astr.	143	36.6% 49.6%	66	16.9% 22.8%	18	4.7% 6.3%	61	15.7% 21.3%	102	26.2%
Basic sciences	1,136	27.5% 36.2%	1,105	26.7% 35.1%	243	5.9% 7.7%	659	16.0% 21.0%	986	23.9%
Other sciences (3)	91	13.0% 17.6%	282	40.3% 54.6%	45	6.5% 8.8%	98	14.0% 18.9%	184	26.3%
All sciences	1,227	25.4% 33.5%	1,386	28.7% 37.9%	289	6.0% 7.9%	757	15.7% 20.7%	1,170	24.2%

(1) Data are estimates of the aggregate totals for all 50 colleges, based on a sample of 22 reporting.

(2) The sample of 22 reporting represents all available data, and INCLUDES patterns of graduate school attendance from seven institutions NOT providing similar data on the class of 1980 as of the first year following degree receipt (see Table I-4).

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

* The first figure in the "%" columns for each discipline represents the unadjusted proportion of all graduates in that discipline with the given outcome for that column. The second figure represents the adjusted proportion excluding graduates for whom outcome is unknown.

** Known not to have attended graduate school.

Table I-6

Patterns of graduate school attendance among science graduates
at the 50 liberal arts colleges

Class of 1980 : first year out (1980-81)

Discipline	Attend Graduate School: science N	science %*	professional N	professional %*	non-science N	non-science %*	No Grad. School ** N	No Grad. School ** %*	Outcome Unknown N	Outcome Unknown %*
Biology	246	13.5% 17.7%	461	25.1% 33.2%	57	3.1% 4.1%	625	34.1% 45.0%	443	24.2%
Chemistry	200	20.8% 22.8%	321	33.5% 36.6%	29	3.0% 3.3%	329	34.2% 37.4%	82	8.6%
Geology	107	25.9% 29.4%	0	.0 .0	18	4.3% 4.9%	239	57.8% 65.7%	50	12.1%
Mathematics	111	15.9% 20.7%	64	9.2% 12.0%	25	3.6% 4.7%	336	48.2% 62.7%	161	23.1%
Physics & Astr.	154	34.7% 42.6%	57	12.9% 15.8%	32	7.3% 8.9%	118	26.6% 32.7%	82	18.5%
Basic sciences	818	18.8% 23.2%	904	20.8% 25.6%	161	3.7% 4.6%	1,646	37.9% 46.7%	818	18.8%
Other sciences (3)	46	10.3% 14.8%	100	22.2% 31.8%	7	1.6% 2.3%	161	35.7% 51.1%	136	30.2%
All sciences	864	18.0% 22.5%	1,004	20.9% 26.1%	168	3.5% 4.4%	1,807	37.7% 47.0%	954	19.9%

(1) Data are estimates of the aggregate totals for all 50 colleges, based on a sample of 14 reporting.

(2) The sample of 14 reporting represents all and only those colleges reporting patterns of graduate school attendance on the class of 1980 both as of one year following degree receipt AND as of five years after degree receipt (see Table I-7).

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

* The first figure in the "%" columns for each discipline represents the unadjusted proportion of all graduates in that discipline with the given outcome for that column. The second figure represents the adjusted proportion excluding graduates for whom outcome is unknown.

** Known not to have attended graduate school.

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Table I-7

Patterns of graduate school attendance among science graduates
at the 50 liberal arts colleges

Class of 1980 : outcomes to date (85-86)

	Attend Graduate School						No Grad. School **		Outcome Unknown	
	science		professional		non-science					
Discipline	N	%*	N	%*	N	%*	N	%*	N	%*
Biology	400	21.6% 27.9%	668	36.1% 46.6%	121	6.6% 8.5%	243	13.1% 17.0%	418	22.6%
Chemistry	279	28.1% 32.2%	396	39.9% 45.9%	39	4.0% 4.5%	150	15.1% 17.4%	129	12.9%
Geology	207	56.9% 71.6%	14	3.9% 4.9%	21	5.9% 7.4%	46	12.7% 16.0%	75	20.6%
Mathematics	179	24.2% 33.8%	104	14.0% 19.6%	50	6.8% 9.5%	196	26.6% 37.2%	211	28.5%
Physics & Astr.	179	39.7% 52.1%	86	19.0% 25.0%	25	5.6% 7.3%	54	11.9% 15.6%	107	23.8%
Basic sciences	1,243	28.3% 36.0%	1,268	28.8% 36.7%	257	5.8% 7.4%	689	15.7% 19.9%	939	21.4%
Other sciences (3)	71	15.6% 22.2%	182	39.8% 56.7%	18	3.9% 5.6%	50	10.9% 15.6%	136	29.7%
All sciences	1,314	27.1% 34.8%	1,450	29.9% 38.4%	275	5.7% 7.3%	739	15.2% 19.6%	1,075	22.1%

(1) Data are estimates of the aggregate totals for all 50 colleges, based on a sample of 14 reporting.

(2) The sample of 14 reporting represents all and only those colleges reporting patterns of graduate school attendance on the class of 1980 both as of one year following degree receipt AND as of five years after degree receipt (see Table I-6).

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

* The first figure in the "%" columns for each discipline represents the unadjusted proportion of all graduates in that discipline with the given outcome for that column. The second figure represents the adjusted proportion excluding graduates for whom outcome is unknown.

** Known not to have attended graduate school.

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Table I-8

Patterns of graduate school attendance among science graduates
at the 50 liberal arts colleges

Class of 1985 : first year out (1985-86)

Discipline	Attend Graduate School: science N	science % *	professional N	professional % *	non-science N	non-science % *	No Grad. School ** N	No Grad. School ** % *	Outcome Unknown N	Outcome Unknown % *
Biology	297	18.0% 26.1%	397	24.0% 34.9%	38	2.3% 3.4%	404	24.5% 35.6%	516	31.2%
Chemistry	263	32.6% 41.6%	175	21.7% 27.8%	19	2.4% 3.1%	174	21.6% 27.5%	175	21.7%
Geology	87	30.0% 40.5%	5	1.8% 2.4%	5	1.8% 2.4%	118	40.5% 54.8%	76	26.0%
Mathematics	136	16.3% 24.1%	39	4.6% 6.9%	53	6.4% 9.4%	336	40.4% 59.6%	269	32.3%
Physics & Astr.	129	29.2% 50.0%	40	9.1% 15.6%	8	1.9% 3.2%	81	18.2% 31.2%	185	41.7%
Basic sciences	912	22.7% 32.5%	656	16.3% 23.4%	124	3.1% 4.4%	1,112	27.6% 39.7%	1,220	30.3%
Other sciences (3)	175	9.8% 22.5%	106	5.9% 13.6%	25	1.4% 3.2%	471	26.4% 60.6%	1,004	56.4%
All sciences	1,087	18.7% 30.4%	762	13.1% 21.3%	149	2.6% 4.2%	1,583	27.3% 44.2%	2,224	38.3%

(1) Data are estimates of the aggregate totals for all 50 colleges, based on a sample of 39 reporting.

(2) The sample of 39 reporting represents all available data, and includes patterns of graduate school attendance from a number of institutions not providing similar data on the class of 1980.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

* The first figure in the "%" columns for each discipline represents the unadjusted proportion of all graduates in that discipline with the given outcome for that column. The second figure represents the adjusted proportion excluding graduates for whom outcome is unknown.

** Known not to have attended graduate school.

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Table I-9

Six Measures of Student Outcome :

Proportional production of scientists earning NSF Fellowships and doctorates in the sciences, holding various honorary memberships, and authoring highly-cited research

The 50 liberal arts colleges, and the 20 top-rated universities, by institution

	N.S.F. Fellowships (1976 through 1983)		Earned Doctorates in Emp. & Life Sciences (1950 through 1980)		A.M.W.S. Membership (All Post-War Alumni)	
Rank	Institution	%	Institution	%	Institution	%
1	Cal. Tech.	5.24%	Cal. Tech.	37.47%	Cal. Tech.	15.40%
2	* Swarthmore	2.41%	* Harvey Mudd	37.24%	M.I.T.	6.50%
3	* Harvey Mudd	2.28%	M.I.T.	18.73%	* Harvey Mudd	6.04%
4	M.I.T.	2.11%	* Reed	12.76%	* Reed	5.03%
5	Princeton	1.83%	UC - San Diego	10.60%	* Swarthmore	4.27%
6	Harvard	1.68%	Chicago	9.74%	Chicago	3.72%
7	* Reed	1.36%	* Swarthmore	8.25%	* Haverford	3.32%
8	Chicago	1.08%	* Haverford	7.47%	* Wabash	3.31%
9	Yale	1.00%	Carnegie-Mellon	7.15%	* Wesleyan	3.15%
10	* Pomona	.95%	* Wabash	6.35%	* Oberlin	3.11%
11	* Bryn Mawr	.81%	* Pomona	6.14%	* Pomona	2.96%
12	* Haverford	.79%	Cornell	6.03%	* Amherst	2.94%
13	* Carleton	.78%	* Carleton	5.87%	* Carleton	2.65%
14	Cornell	.74%	* Oberlin	5.84%	Harvard	2.50%
15	Stanford	.71%	Princeton	5.48%	* Kalamazoo	2.14%
16	* Oberlin	.63%	* Kalamazoo	5.13%	Princeton	2.05%
17	* Macalester	.58%	Harvard	5.09%	* Grinnell	1.91%
18	* Earlham	.53%	* Amherst	5.08%	* Frank & Marsh	1.85%
19	Brown	.52%	* Earlham	4.34%	* Earlham	1.83%
20	* Whitman	.46%	* Wooster	4.29%	* Williams	1.80%
21	* Amherst	.44%	* Frank & Marsh	4.11%	Cornell	1.77%
22	* Grinnell	.40%	* Grinnell	4.07%	Columbia	1.71%
23	* Wesleyan	.38%	Columbia	4.07%	* Union	1.70%
24	Washington U.	.35%	Yale	4.03%	* Wooster	1.64%
25	UC - San Diego	.30%	* Union	4.03%	Yale	1.63%
Colleges in top 10		4		5		7
Colleges in top 20		11		12		15
Colleges in top 25		14		15		17
Among only the 25 most Productive (above) :						
College Productivity		.80%		5.96%		2.62%
Univ. Productivity		1.06%		7.61%		2.81%
All 50 Cols. & 20 Univs.						
50 College Productivity		.26%		3.21%		1.32%
20 Univ. Productivity		.38%		3.99%		1.33%

(Cont'd. next page)

Table I-9 (Cont'd.)

Six Measures of Student Outcome :

Membership in Who's Who in Science & Tech. (All Post-War Alumni)		I.S.I. Citation Index The 1,000 Most-Cited Authors (1965 through 1978)		Membership in National Academy of Sciences (Among alumni graduated 1946 through 1969)	
Institution	%	Institution	%	Institution	%
Cal. Tech.	4.78%	* Swarthmore	.137%	Cal. Tech.	.443%
Chicago	1.70%	Chicago	.133%	Harvard	.175%
M.I.T.	1.27%	Harvard	.092%	Chicago	.161%
Harvard	1.21%	Cal. Tech.	.091%	* Swarthmore	.161%
* Harvey Mudd	1.01%	* Wabash	.080%	M.I.T.	.156%
* Wesleyan	.90%	Columbia	.061%	* Reed	.115%
Yale	.73%	* Wesleyan	.058%	* Wesleyan	.068%
Princeton	.72%	* Haverford	.057%	* Carleton	.060%
* Swarthmore	.69%	* Kenyon	.052%	* Hamilton	.051%
Columbia	.60%	Yale	.051%	* Amherst	.049%
UC - San Diego	.53%	* Carleton	.043%	Princeton	.048%
Cornell	.49%	M.I.T.	.040%	Columbia	.047%
* Amherst	.47%	Princeton	.036%	Cornell	.046%
Stanford	.46%	* Union	.034%	* Haverford	.039%
* Reed	.43%	* Oberlin	.034%	Yale	.038%
* Haverford	.43%	Cornell	.031%	* Pomona	.035%
* Wellesley	.37%	* Reed	.027%	Carnegie-Mellon	.027%
* Oberlin	.33%	* Amherst	.025%	UC - Berkeley	.024%
Brown	.30%	* Williams	.024%	* Oberlin	.024%
* Barnard	.30%	* Hamilton	.019%	* Bates	.024%
* Pomona	.28%	* LaFayette	.019%	* Davidson	.023%
U. Penn.	.28%	U. Penn.	.019%	* Antioch	.023%
Wisconsin	.25%	U.C.L.A.	.018%	* Grinnell	.022%
Illinois	.24%	* Bates	.017%	* Bowdoin	.021%
* Wabash	.24%	* Bowdoin	.016%	* Hope	.019%
	3		5		6
	9		12		10
	11		15		15
	.44%		.040%		.046%
	.55%		.043%		.070%
	.15%		.012%		.015%
	.37%		.020%		.031%

Table I-10

Aggregate data on six measures of student outcome :

The 50 liberal arts colleges and the 20 top-rated universities

	50 Colleges			20 Universities		
NSF Fellowships :	N of NSF Fellows	N of B.A.'s	% of Grads awarded NSF Fell's	N of NSF Fellows	N of B.A.'s	% of Grads awarded NSF Fell's
1976	48	20,640	.23%	216	49,693	.43%
1977	79	20,263	.39%	202	48,228	.42%
1978	49	21,006	.23%	208	48,360	.43%
1979	46	20,744	.22%	172	48,831	.35%
1980	53	21,183	.25%	172	48,002	.36%
1981	54	21,373	.25%	160	49,291	.32%
1982	66	22,04½	.30%	194	51,019	.38%
1983	50	22,010	.23%	175	51,930	.34%
1976-83	445	169,263	.26%	1,499	395,354	.38%
Earned Doctorates in Empirical & Life Sci. :	N of Sci PhD's	N of BA's *	% of Grads earning Sci PhD's	N of Sci PhD's	N of BA's *	% of Grads earning Sci PhD's
1951-80 **	13,303	414,467	3.21%	42,132	1,055,151	3.99%
Membership in American Men & Women of Science :	N members in AMWS	N of BA's *	% of Grads members in AMWS	N members in AMWS	N of BA's *	% of Grads members in AMWS
1946-81 ***	5,487	414,467	1.32%	13,997	1,055,151	1.33%
Membership in Who's Who in Frontier Science & Tech. :	N members Who's Who	N of BA's *	% of Grads members Who's Who	N members Who's Who	N of BA's *	% of Grads members Who's Who
1946-81 ***	621	414,467	.15%	3,915	1,055,151	.37%
I.S.I. Citation Index 1,000 Most-Cited Authors	N of Highly Cited Authors	N of BA's *	% of Grads Highly Cited	N of Highly Cited Authors	N of BA's *	% of Grads Highly Cited
1965-78 ****	48	414,467	.012%	216	1,055,151	.020%
Membership in National Academy of Sciences :	N members in NAS	N of BA's (48-69)	% of Grads members in NAS	N members in NAS	N of BA's (48 - 69)	% of Grads members in NAS
1945-69 ***	44	297,981	.015%	224	727,800	.031%

* from 1946 - 1976
** Years of PhD receipt
*** Years of BA receipt
**** Years of citation

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Chapter II

The Science Faculty: Teachers and Practicing Scientists

The 1985 Report demonstrated unequivocally the centrality of the faculty at these colleges to superb science education. In summary that report showed:

* The opportunity to sustain an active research program attracts a university caliber faculty to these undergraduate colleges. Members of such faculties regularly conduct and publish research; 60% have averaged one article published in each of the past five years.

* These productive, practicing scientists teach students at all levels of the curriculum, from introductory courses to research apprenticeships.

* Students themselves are actively engaged in scientific research. Nearly 30% of all scientific articles produced at the colleges are jointly authored by undergraduate students and their faculty mentors.

This chapter examines some basic characteristics of the faculty who meet daily with talented and promising undergraduates. It also examines changes in the science faculties that have occurred over the past decade, and provides some insight into the dynamics of faculty flow.

The results reported here are based upon data submitted by 44 of the participating institutions. The analysis is limited to those faculty occupying "tenure-track" positions. Thus, the study does not report on those individuals holding temporary appointment, those replacing faculty on leave or those supported by external funds. For the most part we will describe the entire population rather than developing a profile for the typical institution.

Profile of the 1985-86 Science Faculty

There are some 1,600 tenure-track positions in the basic sciences at the 50 participating institutions. The information presented here describes the characteristics of 1,385 faculty members who fill 1,435 positions (the remaining positions are currently vacant).

These faculty are:

* Overwhelmingly male (89%).

* Virtually all white (96%). There are 3% of Asian descent; less than 1% black.

* Mostly tenured (69%).

* Almost exclusively full-time (97%).

* Relatively old (average age is 44 years).

There are a few notable differences among the various academic disciplines. The highest percentage of women is found in Biology (18%), the lowest percentage in Physics & Astronomy (7%). There are so few black science faculty -- only 11 among the 44 institutions -- that departmental comparisons are meaningless. Other minority faculty are about equally distributed among the departments, with the exception of Geology, in which no faculty member is of Asian or Hispanic background.

The faculty presence in classrooms and laboratories is therefore overwhelmingly male and white. Opportunities for students to witness women and minorities as practicing scientists are severely limited. To the extent that the presence of role-models of one's own gender or race influences motivation, academic performance, or career selection, female and black students remain at a significant disadvantage.

Physics & Astronomy has the highest tenure ratio (75%), while the Other Science departments (largely Computer Science and Engineering) has the lowest (56%). The distribution among the academic ranks mirrors the tenure ratio fairly well.

The average age of the current science faculty is 44.4 years, and the average number of years of service is 14.0. The typical interval between the award of the bachelor's degree and the doctorate is 6.9 years, the interval between the Ph.D. and appointment to the faculty 2.3 years, and from appointment to tenure 5.3 years. These intervals correspond to national norms.

The age distribution is hardly uniform. There are relatively few faculty below 30 and disproportionately few above age 55. Responding both to the post-war baby boom and the rush toward coeducation, many of these colleges expanded in enrollment during the 1960's and early 1970's. Their faculties increased correspondingly experiencing an influx of new, younger faculty. These scientists are now in their 40's and 50's and comprise a bulge in the age distribution. The colleges can therefore expect relatively few retirements over the next decade, followed by an accelerated retirement rate in the decade following. These demographic facts, if present not only at these colleges but nationally as well (there are sufficient data to support this proposition), will have a major influence on the demand for academic scientists for at least two decades.

Given what is known about the scientific manpower pipeline, the supply of scientists may very well be low just as the demand increases markedly. With the long latencies in the system described above, it is not now too early to take concerted action to increase the flow of capable scientists. Educating talented, highly productive scientists is precisely what these leading undergraduate liberal arts colleges do so exceptionally well. They attract significant numbers of able and motivated students, nurture their interest in science, expose them to a professionally active faculty, advance their disciplinary knowledge, hone their research skills, and send large numbers to the leading graduate departments.

The baccalaureate degree origins of the faculty holding appointment at these institutions reveal undergraduate training at the country's leading colleges and universities. There is an excellent representation of the participating institutions. About 30% received their undergraduate training at one of the conference colleges; 18% were educated as undergraduates at one of the 20 leading universities. In absolute numbers the most frequent baccalaureate institutions are: Harvard, Michigan, Oberlin, Dartmouth, Williams, and Amherst. Over 46% of these faculty received their graduate training at universities with the highest-rated graduate programs. The universities having the largest number of graduates on the conference institution's faculties are: Harvard, Wisconsin, the University of California at Berkeley, Yale, Illinois, and Michigan.

Changes in the Faculty Composition

How have the faculties at these institutions changed over time? While it is useful to have a snapshot of the faculty at a single point in time, it is obviously important to understand changes that have occurred. In this section we describe changes in tenure-track positions, and the faculty who hold them, in the years since 1975-76.

The highlights are these:

* There are now 11% more tenure-track positions.

* The percentage of women has nearly doubled (from 6.4% to 11.5%).

* While the overall minority presence has increased, the number of black faculty has remained constant.

* The tenure ratio has remained constant (at 69.6%).

* Part-time appointments have become more frequent, increasing from 1.7% to 3.3%.

During a period when the number of enrolled freshmen at these colleges increased by about 4%, the number of tenure-track positions in the sciences has increased by 11%. The growth rate in faculty positions has been largest in Other Sciences (43% from a small base) and in Mathematics (15% from a large base). The least growth has been in Chemistry (5%).

Over the past decade colleges have generally sought to expand the number of women and minorities on their faculties. These efforts have met with much more success for women than for minorities. Indeed, the evidence reveals than the number of women has nearly doubled (an increase from 80 to 158, or a growth rate of 98%), bringing the percentage of women to about 12%. There has been an increase in Asians from 15 to 36, an 140% increase. However, despite a frequently articulated goal of attracting larger numbers of black faculty to these colleges, the number of black scientists has remained constant at 11.

The tenure ratio has remained steady at 69.6%. However, the average age has increased by more than 2.5 years, from 41.9 to 44.4. The faculty is aging.

Part-time tenure-track appointments have grown in number, increasing from 21 to 46, or from 1.7% of all positions to 3.3%. Less than full-time appointments are most common in Biology and Other Sciences, least frequent in Physics & Astronomy.

Science Faculty Turnover

In order to gain further insight into the nature of these changes in the faculty over the past decade, we have analyzed the turnover of faculty. Institutions provided information about each faculty member who left their colleges -- through retirement, resignation, non-reappointment, or death. Data about all new appointments, whether to existing positions or to newly created ones, were obtained as well. In the discussion that follows these are termed "departures" and "arrivals" respectively.

Arrival and departure rates, when expressed as a percentage of the average number of faculty in each category, show some variations among the different categories. Since number of positions has increased, the arrival rates typically exceed the departure rates. The highlights are these:

* Rates vary somewhat by discipline.

* Turnover among female faculty is substantial.

* Minority turnover is slightly lower than for whites.

Because several different individuals could have held a particular position over the ten year period, the net changes derived from comparing the faculty in 1975-76 to the faculty in 1985-86 do not correspond to those derived from the turnover data directly. About 67% of the positions were held by the same individual for the entire period; 24% of the positions were held by two individuals; 8% by three; and 2% by four different people in ten years.

A simple method of describing turnover is to compute arrival and departure rates. The arrival rate is defined as the number of individuals who have joined the faculty over the ten year period divided by the average number of tenure-track positions during those years. The departure rate is defined similarly. Annual rates may be obtained by computing these metrics for each year under study.

Arrival and departure rates vary by department, with the highest in Other Sciences (108% arrival and 72% departure) and the lowest in Physics & Astronomy (53% and 44% respectively). Rates among the other departments resemble the averages for the faculties as a whole (66% arrival and 53% departure). These data suggest that turnover is greatest in the less mature and consequently more volatile fields.

From a variety of perspectives the very substantial departure rates for female faculty is troubling. The doubling in the number of women science faculty has been achieved only through adding women to the faculty at a rate nearly three times that of men (160% vs. 60%), coupled with a loss rate about twice that of men (84% vs. 50%). This finding raises important questions about the reasons why women leave these colleges much more frequently than men. The available data are not sufficient to answer even the most obvious of these questions. Certainly those responsible for faculty personnel management should investigate this situation further.

Given the paucity of minority faculty, not much can be concluded from the arrival and departure rates for faculty of different ethnic backgrounds. It does appear that the institutions are successfully attracting and retaining those of Asian descent.

The vacancy rate, that is the proportion of tenure-track positions that are either held by a temporary appointment (excluding leave replacements) or are unfilled in a given year, has increased slightly from 3.4% to 3.9%.

Science Faculty Attrition

Losses from the faculty arise from several reasons. Expressed in annual terms as a percentage of the number of tenure-track positions these losses average: retirement (1.2%), resignation (2.1%), non-reappointment (1.2%), and death (0.1%). Thus the colleges must replace about 4.7% of the science faculty each year.

Clearly, these rates vary by tenure status. Very few non-tenured faculty retire and virtually all non-reappointments are among non-tenured individuals. Resignations are more frequent among untenured than tenured faculty.

Given these facts, it is hardly surprising that the ages at departure vary according to the reason for leaving the institution. The data are presented both in tabular and graphic form.

Table II-1. Characteristics of the 1985-86 Science Faculty

Department	Total Positions	%	Per College
Biology	333	23.2%	7.6
Chemistry	283	19.7%	6.4
Geology	118	8.2%	2.7
Mathematics	346	24.1%	7.9
Astronomy & Physics	236	16.4%	5.4
Other	119	8.3%	2.7
Total	1,435	100.0%	32.6

Sex	Faculty	%	Per College
Female	158	11.5%	3.6
Male	1,221	88.5%	27.8
Total	1,379	100.0%	31.3

Race			
Non-resident alien	4	0.3%	0.1
Black	11	0.8%	0.3
Asian	36	2.6%	0.8
Hispanic	2	0.1%	0.0
White	1,330	96.2%	30.2
Total	1,383	100.0%	31.4

Rank			
Professor	653	47.4%	14.8
Associate	324	23.5%	7.4
Assistant	388	28.1%	8.8
Instructor	14	1.0%	0.3
Total	1,379	100.0%	31.3

Tenure Status			
Tenured	964	69.6%	21.9
Untenured	421	30.4%	9.6
Total	1,385	100.0%	31.5

Full- and Part-time			
Full-time	1,339	96.7%	30.4
Part-time	46	3.3%	1.0
Total	1,385	100.0%	31.5

Table II-2. Characteristics of the 1985-86 Science Faculty -- By Department

Sex	Biology	Chem	Geology	Math	Physics Astron	Other	Total
Female	59	27	11	39	15	7	158
%	18.3%	9.9%	9.9%	11.5%	6.5%	6.7%	11.5%
Male	264	245	100	299	216	97	1,221
%	81.7%	90.1%	90.1%	88.5%	93.5%	93.3%	88.5%
Race							
Non-resident alien	1	0	0	2	1	0	4
%	0.3%	0.0%	0.0%	0.6%	0.4%	0.0%	0.3%
Black	5	2	1	2	0	1	11
%	1.5%	0.7%	0.9%	0.6%	0.0%	0.9%	0.8%
Asian	7	9	0	10	5	5	36
%	2.2%	3.3%	0.0%	3.0%	2.2%	4.6%	2.6%
Hispanic	0	0	0	2	0	0	2
%	0.0%	0.0%	0.0%	0.6%	0.0%	0.0%	0.1%
White	310	261	110	322	225	102	1,330
%	96.0%	96.0%	99.1%	95.3%	97.4%	94.4%	96.2%
Rank							
Professor	153	141	52	141	127	39	653
%	47.4%	51.8%	46.8%	41.7%	55.0%	35.8%	47.2%
Associate	88	57	15	86	50	28	324
%	27.2%	21.0%	13.5%	25.4%	21.6%	25.7%	23.4%
Assistant	80	73	39	107	54	35	388
%	24.8%	26.8%	35.1%	31.7%	23.4%	32.1%	28.0%
Instructor	0	1	4	2	0	7	14
%	0.0%	0.4%	3.6%	0.6%	0.0%	6.4%	1.0%
Other	2	0	1	2	0	0	5
%	0.6%	0.0%	0.9%	0.6%	0.0%	0.0%	0.4%
Tenure							
Tenured	240	192	71	226	174	61	964
%	74.3%	70.6%	64.0%	66.9%	75.3%	55.5%	69.6%
Untenured	83	80	40	112	57	49	421
%	25.7%	29.4%	36.0%	33.1%	24.7%	44.5%	30.4%
Full- and Part-time							
Full-time	240	225	93	251	178	74	1,061
%	94.9%	97.0%	95.9%	98.0%	98.3%	94.9%	96.7%
Part-time	13	7	4	5	3	4	36
%	5.1%	3.0%	4.1%	2.0%	1.7%	5.1%	3.3%

Table II-3. Characteristics of the 1985-86 Science Faculty -- By Sex

Department	Female	%	Male	%	Total
Biology	59	37.3%	264	21.6%	323
Chemistry	27	17.1%	245	20.1%	272
Geology	11	7.0%	100	8.2%	111
Mathematics	39	24.7%	299	24.5%	338
Astronomy & Physics	15	9.5%	216	17.7%	231
Other	7	4.4%	97	7.9%	104
Total	158	100.0%	1,221	100.0%	1,379
Race					
Non-resident alien	2	1.3%	2	0.2%	4
Black	0	0.0%	11	0.9%	11
Asian	4	2.5%	31	2.5%	35
Hispanic	0	0.0%	2	0.2%	2
White	152	96.2%	1174	96.2%	1,326
Total	158	100.0%	1220	100.0%	1,378
Rank					
Professor	20	12.7%	631	51.7%	651
Associate	35	22.2%	287	23.5%	322
Assistant	100	63.3%	287	23.5%	387
Instructor	3	1.9%	11	0.9%	14
Other	0	0.0%	5	0.4%	5
Total	158	100.0%	1,221	100.0%	1,379
Tenure Status					
Tenured	55	34.8%	907	74.3%	962
Untenured	103	65.2%	314	25.7%	417
Total	158	100.0%	1,221	100.0%	1,379
Full- and Part-time					
Full-time	158	100.0%	1,186	97.1%	1,344
Part-time	11	7.0%	35	2.9%	46
Total	169	107.0%	1,221	100.0%	1,390

Table II-4. Characteristics of the 1985-86 Science Faculty -- Age

Age Distribution	Number	%
20 - 25	2	0.1%
26 - 30	101	7.3%
31 - 35	228	16.5%
36 - 40	221	16.0%
41 - 45	218	15.8%
46 - 50	204	14.8%
51 - 55	174	12.6%
56 - 60	131	9.5%
61 - 65	87	6.3%
66 - 70	13	0.9%
Total	1,379	100.0%

	Mean	S.D.
Age	44.4	10.1
Years of Service	14.0	9.8
Age		
at B.A.	21.8	1.8
at Ph.D.	28.6	3.6
at appointment	31.1	4.8
at tenure	36.2	4.3
Interval		
B.A. to Ph.D.	6.9	3.2
Ph.D. to appointment	2.3	4.6
Appointment to tenure	5.3	2.5

Table II-5. Baccalaureate and Doctoral Degree Origins of the 1985-86 Science Faculty

Baccalaureate	Number	Doctoral	Number
Michigan	29	Harvard	68
Harvard	28	Wisconsin	53
Oberlin	28	UC Berkeley	50
Dartmouth	24	Yale	45
Williams	22	Illinois	42
Amherst	21	Michigan	42
Carleton	19	MIT	34
Pomona	19	Princeton	33
Swarthmore	19	Cornell	32
UC Berkeley	18	Stanford	31
Yale	18	Ohio State	26
Columbia	16	Indiana	25
Stanford	16	Purdue	24
Cal Tech	15	Chicago	23
Ohio State	14	U Washington	23
St Olaf	14	UCLA	22
Wisconsin	14	Massachusetts	21
Case Western	13	Penn State	21
ULCA	13	Cal Tech	20
Cornell U	12	Johns Hopkins	20
Hope	12	Michigan State	20
MIT	12	Penn	20
Union	12	Brown	18
Wheaton (Ill)	12	Minnesota	18
Michigan State	11	Colorado	17
Penn State	11	Columbia	15
Antioch	10	Duke	15
Bucknell	10	Iowa State	15
Princeton	10	Oregon	15
Wooster	10	Kansas	14
CCNY	9	Lehigh	13
Chicago	9	Rutgers	12
Penn	9	Washington State	12
Bowdoin	8	Case Western	11
Earlham	8	Dartmouth	11
Middlebury	8	Iowa	11
Minnesota	8	Rochester	11
U Illinois	8	North Carolina	9
U Washington	8	Pittsburgh	9
Franklin & Marshall	7	Virginia	9
Indiana	7	Arizona	8
Lehigh	7	Northwestern	8
Reed	7	Syracuse	8
Rochester	7	Texas	8
U Connecticut	7	Other	423
Wabash	7		
Other	779	Total	1,385
Total	1,385		

Table II-6. Characteristics of the Science Faculty -- 1975-76 and 1985-86

Department	Positions 1975-76	%	Positions 1985-86	%	Change	Percent Change
Biology	315	24.4%	333	23.2%	18	5.7%
Chemistry	269	20.8%	283	19.7%	14	5.2%
Geology	108	8.4%	118	8.2%	10	9.3%
Mathematics	301	23.3%	346	24.1%	45	15.0%
Astronomy & Physics	217	16.8%	236	16.4%	19	8.8%
Other	83	6.4%	119	8.3%	36	43.4%
Total	1,293	100.0%	1,435	100.0%	142	11.0%

Sex	Faculty 1975-76	%	Faculty 1985-86	%	Change	Percent Change
Female	80	6.4%	158	11.5%	78	97.5%
Male	1,168	93.6%	1,221	88.5%	53	4.5%
Total	1,248	100.0%	1,379	100.0%	131	10.5%
Race						
Non-resident alien	14	1.1%	4	0.3%	(10)	-71.4%
Black	11	0.9%	11	0.8%	0	0.0%
Asian	15	1.2%	36	2.6%	21	140.0%
Hispanic	2	0.2%	2	0.1%	0	0.0%
White	1,207	96.6%	1,330	96.2%	123	10.2%
Total	1,249	100.0%	1,383	100.0%	134	10.7%
Tenure Status						
Tenured	882	69.5%	964	69.6%	82	9.3%
Untenured	387	30.5%	421	30.4%	34	8.8%
Total	1,269	100.0%	1,385	100.0%	116	9.1%
Full- and Part-time						
Full-time	1,248	98.3%	1,339	96.7%	91	7.3%
Part-time	21	1.7%	46	3.3%	25	119.0%
Total	1,269	100.0%	1,385	100.0%	116	9.1%

Table II-7. Age Characteristics of the Science Faculty -- 1975-76 and 1985-86

Age Distribution	1975-76	%	1985-86	%	Change
20 - 25	6	0.5%	2	0.1%	-4
26 - 30	131	10.7%	101	7.3%	-30
31 - 35	268	21.9%	228	16.5%	-40
36 - 40	214	17.5%	221	16.0%	7
41 - 45	186	15.2%	218	15.8%	32
46 - 50	149	12.2%	204	14.8%	55
51 - 55	132	10.8%	174	12.6%	42
56 - 60	92	7.5%	131	9.5%	39
61 - 65	41	3.3%	87	6.3%	46
66 - 70	6	0.5%	13	0.9%	7
Total	1,225	100.0%	1,379	100.0%	154

	1975-76 Mean	1975-76 S.D.	1985-86 Mean	1985-86 S.D.	Change
Age	41.9	9.8	44.4	10.1	2.5
Years of Service	12.0	8.5	14.0	9.8	2.0
Age					
at B.A.	22.0	2.1	21.8	1.8	(0.2)
at Ph.D.	28.9	4.5	28.6	3.6	(0.3)
at appointment	30.7	5.0	31.1	4.8	0.4
at tenure	36.6	4.8	36.2	4.3	(0.4)
Interval					
B.A. to Ph.D.	7.0	3.9	6.9	3.2	(0.1)
Ph.D. to appointment	1.6	5.2	2.3	4.6	0.7
appointment to tenure	5.8	2.9	5.3	2.5	(0.4)

Table II-8. Science Faculty Turnover -- 1975-76 to 1985-86

Department	Arrive	%	Depart	%	Net Change
Biology	200	61.7%	167	51.5%	33
Chemistry	162	58.7%	141	51.1%	21
Geology	86	76.1%	69	61.1%	17
Mathematics	231	71.4%	173	53.5%	58
Astronomy & Physics	121	53.4%	100	44.2%	21
Other	109	107.9%	73	72.3%	36
Total	909	66.6%	723	53.0%	186
Sex					
Female	190	159.7%	100	84.0%	90
Male	713	59.7%	602	50.4%	111
Total	903	68.7%	702	53.4%	201
Race					
Non-resident alien	10	111.1%	19	211.1%	-9
Black	7	63.6%	6	54.5%	1
Asian	29	113.7%	9	35.3%	20
Hispanic	2	100.0%	2	100.0%	0
White	857	67.6%	666	52.5%	191
Total	905	68.8%	702	53.3%	203

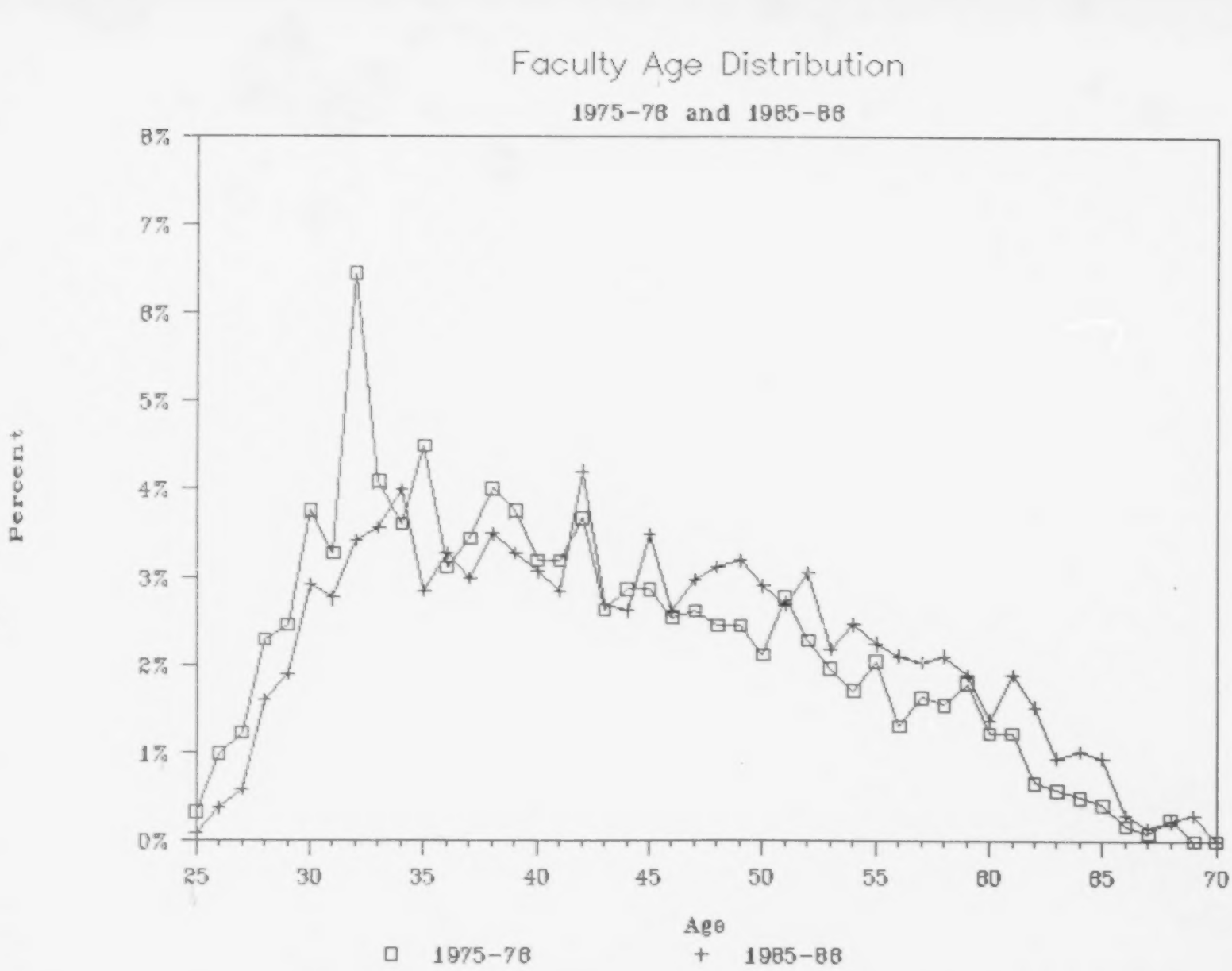
Reason for Departure	Number	Total Rate	Annual Rate
Retirement	168	12.3%	1.2%
Resignation	289	21.2%	2.1%
Death	16	1.2%	0.1%
Non-reappointment	165	12.1%	1.2%
Total	638	46.8%	4.7%

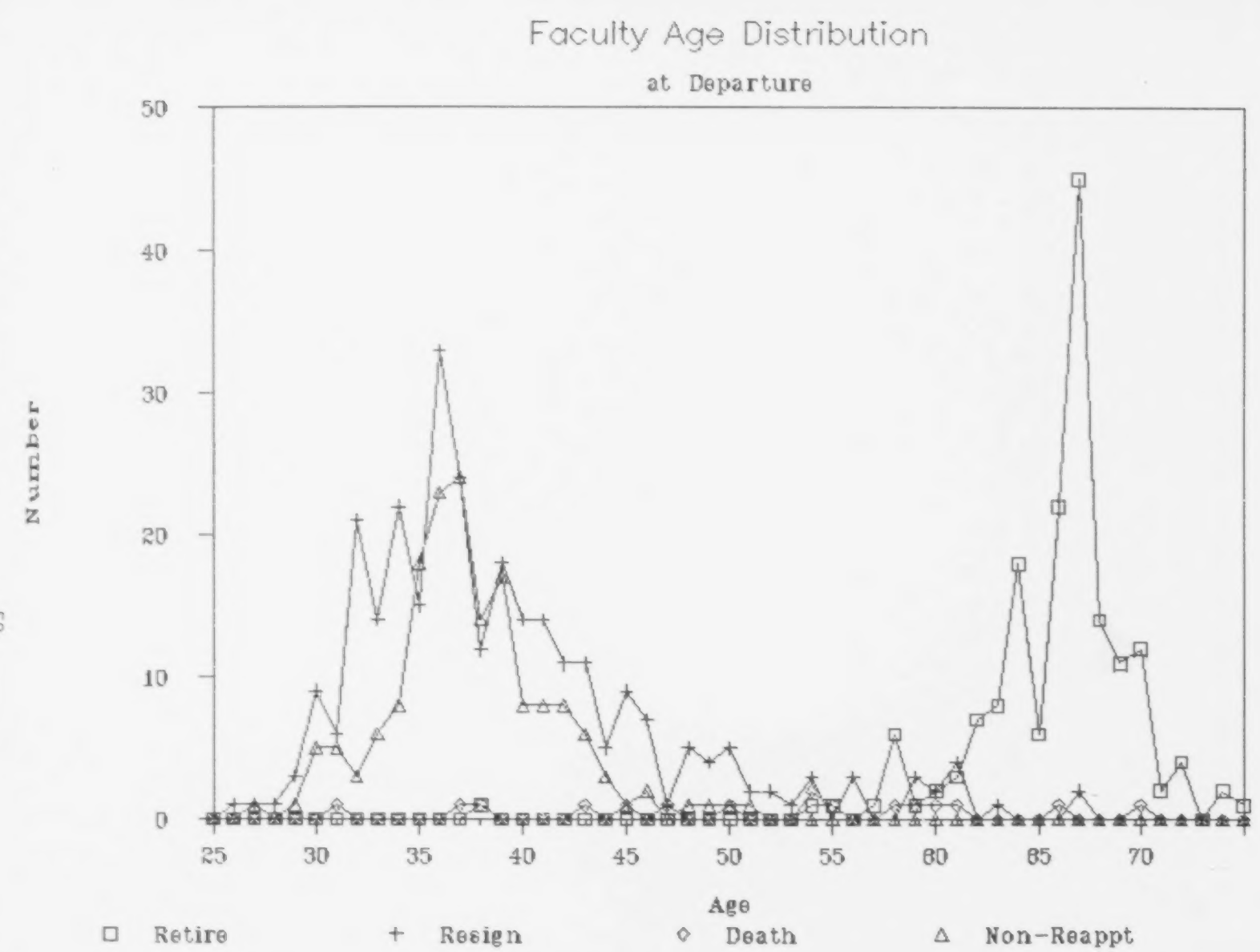
Number of Occupants	Number	%
One	924	66.7%
Two	328	23.7%
Three	110	7.9%
Four	23	1.7%
Total	1,385	100.0%

Table II-9. Age of Departing Faculty and Reasons for Departure

Age Distribution	Retire	Resign	Death	Non-Reappt	Total
25 - 30	0	41	1	15	57
31 - 35	0	106	1	79	188
36 - 40	1	69	1	55	126
41 - 45	0	33	3	12	48
46 - 50	0	18	1	4	23
51 - 55	3	7	3	0	13
56 - 60	19	9	4	0	32
61 - 65	99	3	1	0	103
> 66	46	0	1	0	47
Total	168	288	16	165	637

Age at Departure	Number	Mean	S.D.
Tenured faculty:			
Retirement	148	63.8	3.3
Resignation	90	43.3	7.6
Death	10	53.6	8.8
Non-reappointment	4	44.0	2.8
Sub total	252	55.8	NA
Non-tenured faculty:			
Retirement	20	64.3	7.8
Resignation	199	34.5	5.4
Death	6	43.3	11.7
Non-reappointment	161	35.2	3.8
Sub total	386	36.5	NA
All faculty:			
Retirement	168	63.9	4.1
Resignation	289	37.2	7.4
Death	16	49.8	10.9
Non-reappointment	165	35.4	4.0
Sub total	638	44.1	13.4


Faculty Age Distribution
1975-76 and 1985-86
8%
7%
6%
5%
4%
3%
2%
1%
0%
Percent
25
30
35
40
45
50
55
60
65
70
Age
1975-76
1985-86


Faculty Age Distribution
at Departure
Number
50
40
30
20
10
0
25
30
35
40
45
50
55
60
65
70
Age
Retire
Resign
Death
Non-Reappt

Chapter III

Scientific Equipment and Instrumentation

This chapter presents summary and discussion of the data relevant to the state of scientific equipment and instrumentation at primarily undergraduate colleges of the liberal arts and sciences. The data were obtained chiefly through a survey administered to faculty of the science departments at the 50 selected liberal arts colleges during academic year 1985-86.

Scientific equipment and instumentation are the indispensable tools of the trade both for scientific progress through research and for the imparting of scientific knowledge through laboratory experience. Without both sufficient quantity and quality in the stock of equipment, each of these functions is seriously diminished.

The American Council on Education's National Higher Education Associations' Task Force in its 1985 report[1] identified as,

> "Priority One: Undergraduate Instructional Equipment and Materials. In our view, the primary need of undergraduate institutions is instructional scientific equipment and materials. The serious deficiencies in the research laboratories of universities are reasonably well documented. ... As noted in the 1980 AAU report to the (National Science) Foundation, 'The Research Instrumentation Needs of Universities', the equipment deficiencies of undergraduate instructional laboratories, while less well documented, are equally serious. Important progress has been made in recent years in addressing the research needs of universities, but little has been done to address the purely instructional equipment needs of undergraduate institutions and programs."

In its 1986 report[2] to the National Science Board, the NSB Task Committee on Undergraduate Science and Engineering Education reiterated this need at several points. In discussing the first of its three areas with "the most serious deficiencies in undergraduate science, mathematics and engineering education", specifically, "laboratory instruction", the Task Committee noted that, "Too frequently it (laboratory instruction) is conducted in facilities and with instruments that are obsolete and inadequate." Later, the Task Committee again states, "Reports and testimony to the Committee indicated that much instrumentation in undergraduate laboratories throughout the U.S. is either worn out or obsolete in the face of rapid advances in science and technology."

In August, 1985, the National Science Foundation published the results of a survey it commissioned during 1982 and 1983 on "Academic Research Equipment in Selected Science and Engineering Fields". This report[3], based on data for a sample of instruments known to be in stock at 43 representative universities and 24 medical schools, documents clearly the strengths and weaknesses in the national stock of research equipment in the U.S. university and professional school system.

Given this recent attention devoted to the issue of scientific equipment and instrumentation in undergraduate institutions, and being aware of the pressing needs therein, it is appropriate to present data on the state of the equipment stock at the liberal arts colleges. This chapter presents those data. However, for a full understanding of the results it is necessary to be aware of the methodology of the study, and of the specific caveats of comparing these data on the 50 liberal arts colleges directly to those of the university sample in the NSF-commissioned study. These two subjects are covered explicitly in the Appendix A to this chapter.

The following pages now present the information on the state of scientific equipment and instrumentation at the 50 liberal arts colleges in 1985-86, these science departments' priorities for future instrumentation needs, and the capital investment required to meet these demands. This discussion is organized into three distinct Sections (A, B and C). Each Section is comprised of an initial "Highlights" synopsis of the primary findings, followed by narrative "Details". These detailed discussions reference the appropriate supporting tables (appended to this chapter). The highlights are sufficient to provide the general reader with a summary of the important findings and conclusions from these data.

Chapter III
Section A:

The Current Equipment Stock of the Liberal Arts Colleges

Size, Age, Purchase Costs, Technical Capability, Working Condition and Usage Profile

HIGHLIGHTS :

* Size and Description

  ** Slightly over 800 instrument systems comprise up to the four most important pieces of scientific equipment per science department at the 50 liberal arts colleges.

  ** This number averages approximately 16 instruments reported per institution, and a reporting frequency of approximately three per department.

  ** As judged by key measures of institutional size, this stock of important instrument systems averages approximately 0.5 systems per tenure-track FTE science faculty member, 0.11 per prospective freshman science major, and 0.15 per senior major in the sciences at these institutions.

  ** These systems represent a total original purchase price investment of approximately $26.6 million. This equates to averages of $0.5 million per institution, $17,000 per FTE faculty (approximately the university mean), and $4,000 per senior science major (half the university average per graduate student).

  ** The stock is highly varied, almost defying classification. However, there are concentrations in various electron and light microscopes, various spectrometers, spectrographs and spectrophotometric systems, various nuclear magnetic resonance instruments, observatories and telescopes, scintillation counters, various automated analyzers, x-ray equipment, oscilloscopes and a wide variety of computing equipment for functions ranging from computer science to experiment control and analysis.

* Purchase Costs

  ** Thirty percent of the 50 colleges' important equipment stock originally cost less than $10,000.

  ** Approximately one in ten (12%) cost $75,000 or more.

  ** As measured by aggregate dollar investment, however, those costing less than $10,000 represent only four percent of the total, while those $75,000 and over comprise nearly half (47%).

** There appears to be some disciplinary variance, with chemistry reporting the most expensive equipment (only 13% below $10,000, and 16% $75,000 and above). Mathematics appears to be the least expensive investment at present (62% below $10,000 in cost).

* Age

** Slightly more than half of the current in-use stock of important scientific equipment at the 50 colleges was purchased within the five years prior to the study. One-fifth is aged six-to-ten years, and the remaining one-third is more than 10 years old. This age distribution is repeated for systems in the price range studied by the NSF ($10,000 to $1,000,000).

** The proportion of the 50 colleges' equipment stock in active use aged one-to-five years is similar to that in the universities' stock. However, the liberal arts colleges' stock contains a smaller percentage six-to-ten years old, and a larger proportion aged more than ten years than does that of the universities.

** Mathematics and Other Sciences[4] (i.e., predominantly computer sciences, and some engineering) have the youngest equipment stock, with 87% and 68% respectively in the one-to-five year range. Other disciplines show consistent age patterns, with 40% to 50% in this age range.

* Technical Capability

** Nearly two instrument systems in five at the colleges were reported to be state-of-the art. This compares to 22% of the in-use systems in the NSF study. The difference is very likely a function, at least in part, of differences in sampling metnodologies between the two studies (see Appendix A).

** Fifty-two percent were reported "Adequate", and only ten percent "Inadequate".

** Little disciplinary variance in technical capability is evident, save mathematics and physics/astronomy reporting only 31% and 27% state-of-the-art respectively. Instruments reported in geology, and chemistry's higher-priced equipment, have the highest percentage SOA (44%).

* Current Working Condition

** Two-thirds of all instrument systems reported this year at the 50 liberal arts colleges were rated in "Excellent" working condition.

** Less than one in ten (8%) were reported to be "Poor" or "Inoperable". These profiles are in stark contrast to the NSF data on university systems. Again, unavoidable differences in sampling between the two studies are likely responsible for some portion of this discrepancy.

** Little disciplinary variance appears, save chemistry and Other Sciences (predominantly late-model computing equipment) with 71% and 76% respectively in excellent condition.

** The aggregate profile of working condition for all systems originally priced from $10,000 to $1,000,000 is very similar, but exhibits greater variance among the disciplines.

* Usage Profile

** The 50 liberal arts colleges' scientific equipment overall is approximately equally dedicated to teaching and to research.

** Although some disciplinary differences exist, in general students appear to have extensive access to the scientific equipment and instrumentation at these colleges, even to those classified as state-of-the-art, those in excellent working condition, and those in the high purchase price ranges.

* As would be expected, there are strong correlations between technical capability, working condition, purchase cost and age.

DETAILS :

This section presents the findings relevant to the size, age, technical capability, working condition and usage profile of the important scientific equipment and instrumentation reported present and in use during 1985-86 at the 50 colleges of the liberal arts and sciences. This discussion is drawn principally from the data presented in the associated tables. These tables are typically prepared by discipline, with various sub-totals and a grand total. In most analyses, a first table gives the numbers of all instrument systems reported, and a second provides data on the dollar value of the investment in these systems, since numbers and cost profiles can each be important, and quite different. Finally, a parallel set of tables provides an identical analysis, but limited to instrument systems originally priced $10,000 to $1,000,000 (the price range studied by NSF).

Gross Numbers of Instrument Systems

The total number of important scientific equipment systems reported using these survey methods is estimated to be slightly more than 800 (Table III-1). The highest percentage of these, nearly one-quarter (24%), were reported in departments of physics and astronomy. Slightly fewer (23%) were in chemistry. Roughly one-fifth (21%) were in the biological sciences (typically, general biology). Geology reported 14% of all instrument systems, other sciences 10%, and mathematics the lowest percentage of the total (7%).

The total dollar investment in this equipment (as measured by original purchase price) is substantial: $26.579 million. However, because average costs per instrument vary considerably among the disciplines, the proportion of this monetary total invested in the various science departments differs from the distribution of numbers of equipment each owns. Chemistry reported the highest per instrument price ($43,000) and the highest proportion of the 26.6 million total (30%). Mathematics reported the lowest average instrument costs per system ($20,000) and claims only 4% of the total investment. Other disciplines cluster near $30,000 per instrument reported.

Limiting the analysis to equipment costing $10,000 or more does not produce a substantively different profile of either numbers or total costs (Table III-2). Although these more expensive systems are estimated to number only 562 (70% of all systems), nearly all of the monetary investment is claimed by this equipment: $24.9 million, or 93.7% of the 26.6 million total.

These absolute numbers, while valuable, must be viewed in light of certain key measures of institutional size. Table III-3 presents both the aggregate numbers of all instrument systems and the total dollar investments in them by discipline and calculates these values per institution, per FTE tenure-track science faculty member, per prospective freshman major (Fall, 1985; Table I-1) and per senior major (1984-85; Table I-2). These indices of equipment extensiveness find wide disciplinary variation. The greatest average number of instruments reported per institution appears in physics and astronomy, but the greatest dollar investment per institution is in chemistry. Mathematics shows the lowest per institution averages.

The liberal arts college data on aggregate monetary investment in scientific equipment measured per tenure-track FTE science faculty member finds very close agreement with the comparable ratios in the NSF study:

	Universities 1982 and 1983	Colleges 1985 - 86
Biological sciences	$13,900	$15,000
Physical sciences	$24,800	$24,000
Overall	$14,200	$17,000

If adjustments were made for inflation, most of these comparisons would be even closer, save that for the physical sciences, where the college dollar investment per FTE faculty member appears to be somewhat below the university mean. These data also indicate an overall mean at the colleges of approximately two FTE faculty per reported individual instrument. This ratio too exhibits wide variation among the disciplines.

In contrast to ratios per FTE faculty, however, mean dollar investments in scientific equipment per senior major in the sciences appear to be relatively very low as compared to university investments per graduate student:

	Universities 1982 and 1983	Colleges 1985 - 86
Biological sciences	$11,200	$3,000
Physical sciences	$18,200	$11,000
Overall	$8,000	$5,000

Equipment purchase dollars per prospective freshman major in the sciences are slightly lower yet, and after an adjustment for inflation over the period between the two studies, the college ratios per student would be lower still relative to those of the universities' stock. The data also indicate on the order of only one to two instruments reported per ten senior majors.

When this analysis is restricted to only those systems whose purchase price falls in the NSF study's range, these already very low ratios become even more unfavorable (Table III-4). Finally it must be noted that the NSF ratios are per graduate student, regardless of year of study, while those for the 50 colleges are only per senior major or prospective freshman. As measured per total student demand, these monetary investments and instrument availablity are roughly an order of magnitude below university means (at the graduate level). It could be reasonably argued that a higher investment in equipment per student is required at the graduate level than at undergraduate stage. However, it would appear to be an equally reasonable question to ask whether this dramatically lower level of investment and availability is sufficient to the task of quality undergraduate education in the sciences.

Purchase Costs

Tables III-5 through III-8 present the basic data on original purchase price of the scientific equipment and instrumentation at the 50 colleges of the liberal arts and sciences. Table III-5 displays the number of all instrument systems reported, by discipline, as distributed over four price ranges. Table III-6 indicates the total dollar investment in the instruments in these price categories. Finally Tables III-7 and III-8 limit these analyses to only those instruments with an original purchase price of $10,000 or more.

Slightly less than one-third of all instrument systems reported at the 50 liberal arts colleges in 1985-86 originally cost less than $10,000 (Table III-5). Approximately this same proportion also falls into each of the next two price categories ($10,000 to $24,999, and $25,000 to $74,999). The remainder, approximately one system in ten (12%), originally cost $75,000 or more.

The percentages in each of these price categories is quite different, however, when measured by the total dollar investment (Table III-6). Equipment costing less than $10,000 accounts for only 4% of the $26.6 million total. Each succeedingly higher price category accounts for an increasingly large proportion of the total investment, and the 12% of all instrument systems originally costing $75,000 or more accounts for nearly half (47%) of the $26.6 million total.

Perhaps the most interesting data in these analyses are the variations by discipline. Chemistry has the largest proportion of high-priced equipment, 16% at $75,000 and above, while mathematics has the largest percentage below $10,000 (62%). Fully half (51%) of the aggregate capital investment in instrumentation in chemistry is in equipment originally costing $75,000 or more. Higher still is this proportion for the Other Sciences (68%). And, even though mathematics reports very few items of equipment in this price category, these few instruments still account for the highest proportion of this discipline's aggregate monetary investment as well (39%).

Tables III-7 and III-8 limit these analyses of original purchase costs to equipment in the price range studied by the NSF. These data indicate a somewhat different distribution of instruments over these price categories (as reported by these survey methods) in use at the 50 colleges today than were found in the NSF's random sample at universities (three or so years ago):

	$10,000 - $24,999		$25,000 - $74,999		$75,000 plus	
	Univ	Cols	Univ	Cols	Univ	Cols
Biological sciences	71%	47%	24%	39%	5%	14%
Physical sciences	55%	43%	33%	41%	13%	16%
Overall	64%	45%	28%	38%	8%	17%

Apparently, the 50 colleges' sample, among instrument systems in the $10,000 and above price range, contains a higher proportion of high-cost equipment. This likely is due in some part to inflation, but is likely also the result of the unavoidably different sampling techniques (see Appendix A).

Current Age

The median age of all instrument systems reported at the 50 colleges of the liberal arts and sciences during 1985-86 was five years (Table III-9). The average age was 8.7 years. For equipment classified as "state of the art", the median age was three years, the average 4.0. These median ages overall and for state of the art equipment are in close agreement with the comparable university medians found in the NSF study: six and three years respectively (the former including the 20% of the total stock which was no longer in research use and, thus, generally relatively old.)

There appeared certain notable variation in median age among the disciplines. Mathematics and Other Sciences (often computer science) reported the youngest equipment: each had an overall median age of three years. Other disciplines ranged from six (chemistry) to eight years (geology) in median age of all instrument systems. However, little disciplinary variance was found in median age of equipment reported to be state of the art. For mathematics and physics/astronomy, state of the art instrumentation had a median age of two years. For biological sciences, chemistry and Other Sciences, this median was three years. Geology reported the oldest median state of the art age, four years. Limiting these analyses of age to all and only those systems in the price range studied by the NSF produced median ages one year younger than noted above for the entire stock of several departments, but did not substantively alter the results of median age for state of the art equipment (Table III-10).

Tables III-11 through III-14 provide the numbers of instrument systems reported at the 50 colleges during 1985-86, by discipline, in total and as distributed over three age ranges (1 to 5 years, 6 to 10 years, and over 10 years of age). Again, this analysis is performed both for the numbers on individual pieces of equipment in the stock, and for the aggregate dollar investment in each age category, and is shown first for all systems regardless of initial cost and, second, for only those systems originally costing $10,000 and above (the NSF study price range). Because the age distribution of the liberal arts colleges' instrumentation is almost identical in aggregate to the age distribution of systems originally priced at $10,000 and above, the remaining discussion can be taken to apply in total as well as to systems comparable to those studied by the NSF.

The 50 liberal arts colleges appear to be operating with greater proportions of their most important instruments over ten years old than are the universities. Just over half (54%) of the in-use instrument systems reported at the 50 colleges were purchased within the most recent five years. This compares closely with the 53% for in-use systems found in the NSF university study. However, the universities had only 22% of all equipment aged 10 or more years. For the colleges, this percentage was nearly 30%:

	% aged 1 to 5 Yrs.		% aged over 10 Yrs.	
	Univs.	Cols.	Univs.	Cols.
Biological sciences	49%	44%	23%	37%
Physical sciences	53%	50%	26%	29%
Overall	53%	54%	22%	28%

In each general area, and in total, the colleges' stock appears to be relatively rich in systems more than 10 years old.

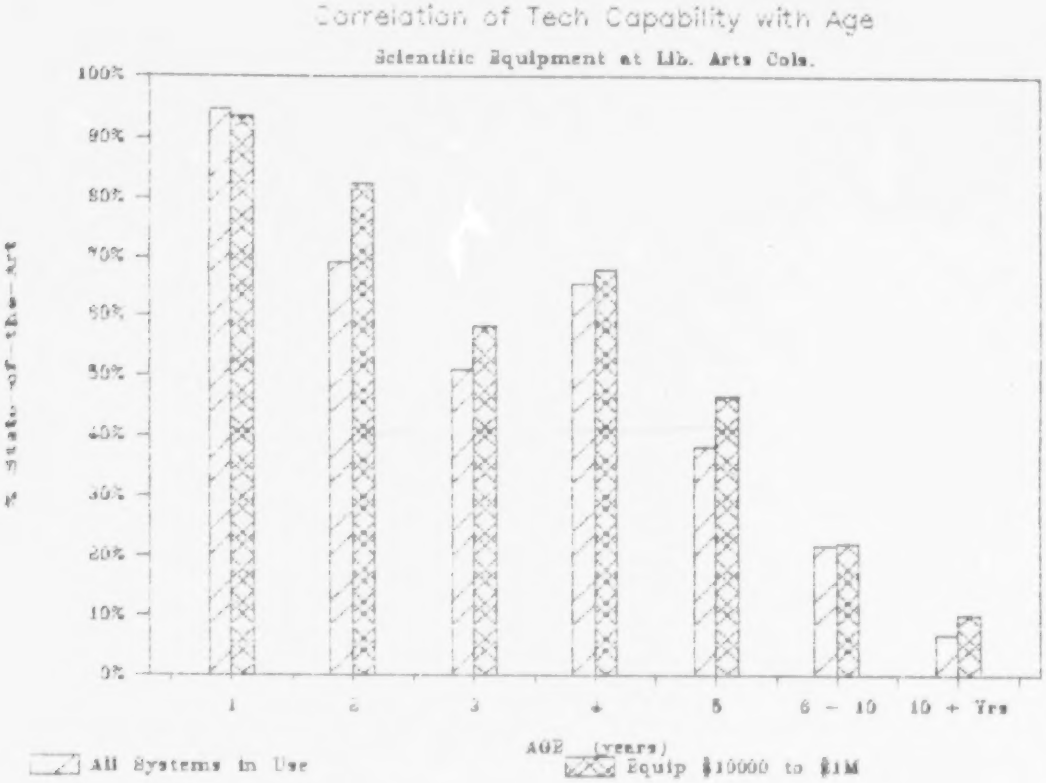
Technical Capability

Science faculty at the 50 colleges of the liberal arts and sciences were asked to rate each of their reported instrument systems on its technical capability (state of the art, adequate, inadequate to research needs). The results of these important ratings are presented in Tables III-15 through III-18. Again, these tables present both numbers of instrument systems by discipline distributed over the ratings of technical capability, followed by the aggregate purchase dollar investments in them, and do so first for all systems reported and, second, for only those originally priced $10,000 and above.

Using this survey method, 38% of all scientific equipment at the 50 colleges was reported to be state of the art. Equipment in the price range studied by the NSF was rated state of the art for 44% of the current, in-use stock. This proportion is exactly twice the 22% rated state of the art among in-use systems in the university sample. At the 50 colleges, 52% of all equipment, and 47% of those in the NSF study's price range, were rated "adequate", leaving only a low 10% and 9% respectively rated to be "inadequate". Here again, it is likely that the differences in sampling techniques is responsible for an indeterminable amount of these differences in profile of technical capability in scientific equipment and instrumentation between these colleges and the universities.

There are several important disciplinary departures from these overall profiles at the 50 colleges. Even though its systems are quite new relative to those of the other disciplines, mathematics reports only 31% of all equipment to be state of the art. This is likely an indication of the extremely rapid advance of technology in this field. Physics/astronomy, however, reports the lowest percentage of its current, in-use stock to be state of the art : 27% (34% of systems priced $10,000 and above). This percentage stands in sharp contrast to all other disciplines (Table III-17), and suggests that special attention may be due to the equipment needs of physics and astronomy.

Because state of the art equipment is of special importance to the scientific community, some data about such systems at the colleges should be noted. As would be expected, age and technical capability are closely related. Mention has been made previously of the median ages of state of the art equipment as contrasted to those rated below state of the art. Tables III-19 and III-20 present the full relationship between system age and its rated technical capability respectively for all instrument systems reported at the 50 colleges, and for only those originally priced $10,000 and above. One key aspect of this relationship is demonstrated graphically below:



This graph indicates the fairly rapid rate at which state of the art systems lose this level of technical capability. It also illustrates an important contrast with the ratings of university equipment, the interpretation of which is not certain. While over 90% of the systems in first year usage at the colleges were rated state of the art, only 43% were so rated in the university stock. In the second usage year, 70% to 80% of the college equipment is rated SOA, while only 36% of the university two year old stock is so classified. This contrast persists (in somewhat decreasing degree) over the entire age scale. This may explain something about the higher proportions rated state of the art at the colleges : perhaps these subjective ratings of technical capability are influenced by the level of technical demand on them as perceived by the faculty in the two very different environments. The level of sophistication demanded by the needs of undergraduate teaching and research may be somewhat lower than that required at the graduate level. Hence, it would be

more likely that a given instrument would be rated state of the art in the college environment than in the universities. This, however, is only one plausible explanation, and the necessarily different sampling methods of the two studies are likely also cause for some of the discrepancy. The data cannot provide a definitive interpretation.

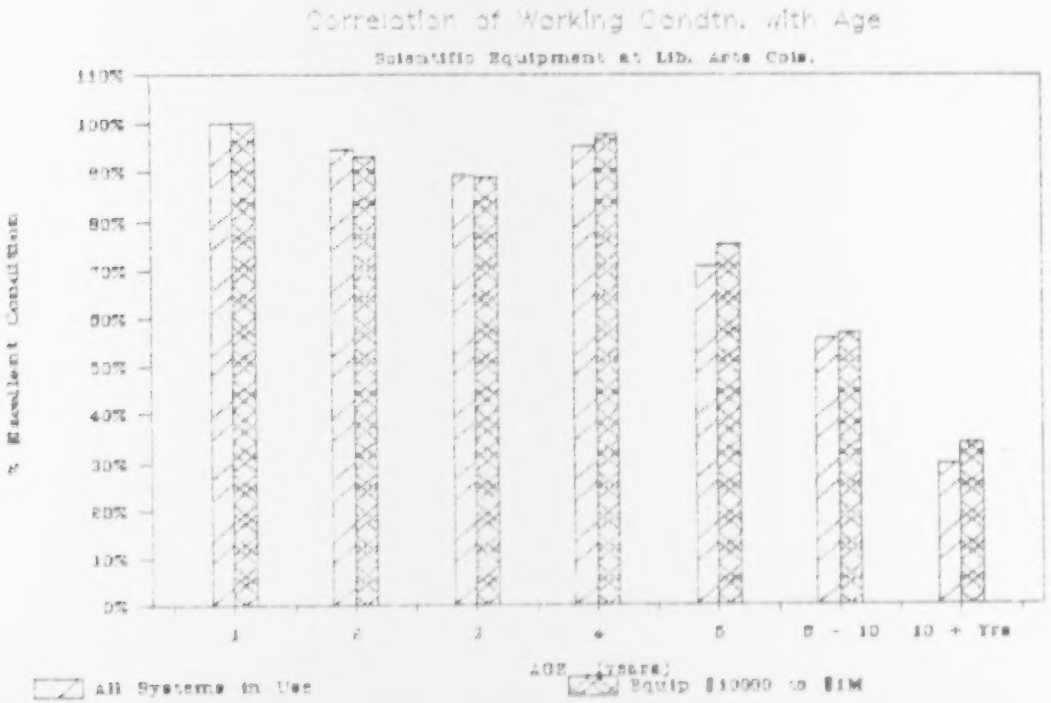
Finally, Tables III-16 and III-18 indicate that the aggregate capital investment in the somewhat more expensive state of the art systems is in excess of what the numbers of such systems alone would indicate.

Current Working Condition

Approximately two-thirds (66%) of all in-use instrument systems reported at the 50 liberal arts colleges in 1985-86 were rated in "excellent" working condition (Table III-21). One-quarter (26%) were "average/adequate", and only 8% "poor" or "inoperable". This distribution is only slightly better when analysis is limited to equipment originally costing $10,000 or more (69%, 24% and 7% respectively, Table III-23). Somewhat in contrast, the NSF study found 52% of all university in-use systems rated "excellent", and 10% rated "poor". Some of this difference is likely due again to different sampling methodology.

Little disciplinary variation was found in the colleges' data on working condition. Other Sciences and chemistry had the highest percentages rated in excellent condition, 76% and 71% respectively. Biology, geology and physics/ astronomy each reported 61% to 62% excellent. The discipline reporting the highest percentage in poor and inoperable condition was geology (14%).

As was true with technical capability, system age is also correlated with operating condition. However, the relationship is somewhat weaker - systems appear to remain in excellent working condition longer than they persist as state of the art equipment:



The details of the relationship between age and working condition are given in Tables III-25 and III-26 respectively for all instrument systems reported at the 50 liberal arts colleges, and for only those in the $10,000 and above price range.

Finally, Tables III-22 and III-24 detail the aggregate dollar investments in scientific equipment at the 50 colleges, by discipline, as distributed over the scale of current working condition. As with state of the art equipment, instruments in excellent condition tend to be somewhat more expensive, doubtlessly in part because they are generally newer, and account for a larger percentage of the total capital investment in equipment (73% to 74%) than their two-thirds proportion of all systems would predict.

Usage Patterns: Teaching and Research

The primary activity in science at the undergraduate stage is the high quality training of able minds in the sciences and scientific methods generally, and in the specifics of one particular discipline. As has often been noted and discussed, this process requires involvement in genuine research (as opposed to prepared laboratory exercises), in addition to classroom experience and prepared laboratories, before leaving the undergraduate step if this training is to be of quality. This intimate and complex synergy between teaching, learning and research applies to both science faculty and their students. Given this essential relationship and the primary function at the undergraduate stage, it is important to examine equipment usage as it is divided between the two synergistic demands of teaching and research. The respondents at the 50 liberal arts colleges were asked to approximate the proportion of each instrument system's time dedicated to these two functions.

As a general rule, all scientific equipment at the 50 colleges of the liberal arts and sciences was reported to be approximately half dedicated to the general activities of teaching, and half dedicated to (faculty, or student-faculty) research. This applies roughly for all systems regardless of purchase costs, system age, technical capability or current working condition (Tables III-27 through III-30 respectively), and is the case for all disciplines.

This general rule is not without exception, however. For the most part, equipment which is less expensive, older, less technically capable and/or in less than excellent working condition tends to be more than half dedicated to teaching activities per se. Equipment below $10,000 in original cost is devoted 63% to teaching (and 33% to research, the remainder being "other" activity). For instrument systems over ten years old, this percentage is also 63%. Teaching activities claim 60% to 62% of the time on equipment rated technically "adequate" and "inadequate", and for that rated in "adequate" working condition.

Nevertheless, the activities of teaching per se claim 48% of the time on systems originally costing $75,000 or more, 51% of the demand on those 1 to 5 years old, 48% of the usage on equipment rated state of the art, and 52% of the instruments in excellent condition. Clearly, students have extensive exposure and access to high quality scientific equipment and instrumentation at the undergraduate level through both their classroom and laboratory experiences at these 50 liberal arts colleges. Indeed, it appears that many have access to

equipment that profiles reasonably closely to that found at the graduate level in U.S. research universities. In addition, since it is clear that junior and senior science majors participate extensively in faculty and independent research, total student access and exposure to the best equipment these colleges have to offer is clearly a central aspect of their undergraduate training at these institutions. Physics/astronomy appears to have the strongest correlation between departure from the 50/50 research/teaching general rule, in the favor of greater dedication to research purposes, and the higher quality levels of its instrumentation. This may be explained in part by this discipline's reporting the lowest percentage of its equipment to be state of the art, thus placing relatively greater demands on this limited resource.

Chapter III
Section B:

Recent Annual Equipment Expenditures,
And Current and Historical Funding Sources

HIGHLIGHTS :

* The 50 colleges of the liberal arts and sciences annually spend approximately $12 million for all expenses involving scientific equipment and instrumentation, slightly less than $250,000 per institution per year (1984-85 data).

* This level of spending averages approximately $50,000 per science department per year, well below the university departmental average of slightly less than $150,000 in 1982 and 1983.

* However, college spending per FTE faculty member today averages $7,900 per annum, very close to the university mean of $8,000 per faculty-level researcher several years ago.

* It appears on average to permit the purchase of one major instrument system per year per science department.

* These absolute expenditures and per unit ratios vary widely over the disciplines, with, perhaps, indication of relatively serious underfunding in physics/astronomy.

* Nearly 90% of these college equipment-related expenditures are used for instrument acquisition. Only 11% go for maintenance and repair, and 8% for costs of operation.

* By far the largest source of these funds is the colleges themselves. In aggregate, they supplied nearly $5 million in 1984-85, 41% of the $12 million total.

* Overall private, non-profit foundations were found to be the second most important funding source for college instrumentation, supplying fully one-quarter of the total.

* Federal funding came in a distant third in funding for college science instrumentation. Only 15% of all 1984-85 college equipment-related expenditures were federally funded. This is in sharp contrast to research university economies where federal funds are the largest single source of instrumentation support, 52%, and the institutions themselves average less than one-third of the total.

* These funding sources also vary greatly by discipline.

DETAILS :

Each department at the 50 liberal arts colleges was asked to report its gross expenditures for all equipment-related functions during academic year 1984-85. Each was also requested to indicate the amount of this total which was spent on acquisition costs, on maintenance and repair, and on operating costs. Data were also collected on the sources for this funding.

Table III-31 presents the estimated aggregate expenditure, by discipline and in total, on all equipment-related functions by the 50 colleges during the most recent fiscal year for which data are currently available. In total, these institutions spent nearly $12.1 million during this year, or approximately one-quarter million ($242,000) on average per institution. The mean annual expenditure per university during 1982 and 1983 found by the NSF study was approximately one order of magnitude larger: $2,127,300. This level of spending at the 50 colleges translates into an average annual expenditure per department (all disciplines) of slightly more than $50,000. The overall average per university department (a better comparative ratio since universities tend to have more than the average 5 departments per institution found at the colleges) was $146,000 three or four years ago, approximately three times the current mean annual expenditure per college department. Another context in which to place this $50,000 mean annual expenditure per college department is the $40,600 average cost per instrument acquired during the past two years. This level of spending thus permits approximately one major system purchase per department per year averaged over these 50 institutions. Finally, the $12.1 million annual total for the colleges indicates an average $7,900 per FTE tenure-track faculty member. This is approximately equal to the $8,000 per faculty-level researcher found in 1982 and 1983 at research universities.

Acquisition is not the only equipment-related spending category, however. Maintenance and repair costs, and the overhead of operating the systems are also involved. The data from the 50 colleges indicate that for every $100 spent on all equipment-related functions, approximately $83 are used for purchasing instruments, $11 for maintenance and repair, and $6 for the costs of operation (Table III-31). The NSF data from universities indicated approximately 20% of all instrument-related expenditures were for maintenance and repair.

To limit this discussion to overall averages would be to ignore the great disciplinary variation in these data, which may indicate significantly more critical conditions for physics/astronomy than for the others. The highest annual expenditures per department on scientific equipment at the 50 colleges appeared in biology and chemistry, approximately $81,000 and $73,000 respectively. The Other Sciences together averaged about $65,000 per department, and geology near $46,000.

Far below these levels is that of physics and astronomy. Here, absolute dollar outlays are approximately half of those in biology and chemistry. This much lower level of spending is spread over 55 departments of physics and astronomy. This indicates an annual equipment-related expenditure per department of just over $30,000, well below one-half the means for biology and chemistry. The mean annual college equipment expenditures per FTE physics faculty are only two-thirds the highly consistent averages per FTE for biology, chemistry and geology (approximately $10,000).

These data are diametrically opposite those at research universities which indicate physics to have among the highest annual expenditures per institution, per department and per researcher. The data do not shed light on reasons for this discrepancy, nor the degree to which it may indicate a genuine problem for this discipline. However, it should be reiterated that physics and astronomy reported the lowest percentage of state of the art equipment, and showed the highest correlations between departure from the 50/50 teaching/research general usage distribution and measures of instrument quality.

Table III-32 indicates how these same annual expenditures on equipment and instrumentation at the 50 liberal arts colleges were funded. Except for Other Sciences, all disciplines report the highest proportion of total expenditures to be internal institutional sources. This percentage ranges from a low of 35.8% for chemistry to a high of 59.5% for mathematics. The overall mean for all disciplines at these colleges was 41% from internal funds, a total of just under $5 million in 1984-85.

The private non-profit sector clearly is a vitally important source of support for college science instrumentation. Among all sources, it ranks second only to the colleges' internal funds. Overall, nearly one-quarter (24%) of the most recent fiscal year's total equipment-related expenditures came from these institutions, a proportion well above that for federal funding. In one year, these 50 colleges received nearly $3 million in non-profit foundational support for scientific instrumentation. Geology reported the largest proportion (53%), and Other Sciences the lowest (6%).

Federal funding of college instrumentation also ranged widely (0.4% to 21.7%), but averaged 15% of total equipment-related expenditure, less than half the overall proportion from internal sources, and slightly more than half the proportion from the private non-profit sector. The total federal dollar contribution for equipment to these colleges in 1984-85 was $1.8 million, an average $36,000 per institution, close to the recent cost of one major instrument system for the average department. These ratios are in stark contrast to the data for universities. There the NSF found 54% of all funds for acquisition to have been from federal sources, and only 32% from the universities themselves. At the 50 colleges, chemistry reported the highest percentage of federal funding (22%).

Business and industry appear to provide widely varying levels of support among the disciplines for college science instrumentation. This ranges from 1% in geology, through 18% for chemistry and mathematics to over one-third (35%) for Other Sciences, thus forming those disciplines principal source of support for scientific equipment. Overall, such private sector contribution totaled $1.6 million, just over 10% of all expenditures for equipment-related costs. By far the bulk of these expenditures in mathematics and Other Sciences is for computing equipment, with a measurable proportion of that in Other Sciences being private sector support of applied work in engineering.

A check of these data on funding sources for one year's annual equipment and instrumentation expenditures is to examine the sources reported for the acquisition costs of all existing "important" equipment. These data are presented in Tables III-33 and III-34, and find some proportions close to those reported overall for recent annual expenditures. Of all important scientific equipment reported currently in use at these 50 colleges, 64% were acquired at least in part with internal, institutional funds. This source supplied 39% of

the total acquisition costs. Federal monies were used to purchase 37% of the instruments, and provided 26% of the aggregate capital investment, a percentage higher than in the most recent single year. Conversely, federal funding was not involved in acquiring nearly two-thirds (63%) of these 50 colleges' instrumentation. All private sources (profit and non-profit) aided the acquisition of 24% of the equipment, and also provided 26% of all monies involved.

Analysis remains to be performed to understand well how these contributions from, and dependencies on, the various sources of funding vary for instruments of different age (i.e., have these sources changed in the level of involvement over time),[5] and for instruments of low and high cost. Aggregate data for all disciplines indicate the following:

	% of Acquisition Costs from :			
	Fed.	Intrnl	Private	Othr
1 - 5 Yrs old	24%	32%	31%	13%
6 - 10 Yrs old	32%	30%	31%	8%
Over 10 Yrs old	33%	40%	24%	4%
less $10,000	20%	55%	19%	5%
$10,000 - $24,999	28%	45%	22%	5%
$25,000 - $74,999	28%	40%	23%	9%
$75,000 or more	28%	26%	34%	12%

It appears that the federal role in college equipment-related expenditures has diminished over the past ten to fifteen years. These funds (proportionately) have been made up chiefly by private and "other" (unspecified) sources. Federal, private and other sources are relatively more important for the acquisition of high-priced instrument systems, the institutional role apparently being the only one to diminish in these ranges. However, costs and instrument age are correlated since inflation in scientific equipment has been high. As of this date, more analysis is required.

Chapter III
Section C:

Ratings of Current Equipment and Services, And Priorities and Investments for the Future

HIGHLIGHTS :

- Approximately one-third of all science departments at the 50 liberal arts colleges indicated their scientific equipment to be "excellent" for teaching. Only half as many indicated it was "insufficient" for these purposes. The remaining 55% rated it "adequate".

- Mathematics and physics/astronomy indicated significantly lower adequacy of their current equipment stock for teaching needs.

- The adequacy of college instrumentation for research purposes was not so highly rated: only one department in five rated it excellent. About half rated it adequate and the remaining one-third insufficient to current research needs.

- Once again, the disciplines of physics and astronomy reported significantly lower adequacy of the current instrumentation stock for research purposes.

- The technical support services available for undergraduate science equipment were rated excellent or adequate by slightly more than half (57%) of the 50 colleges' science departments; the remaining 43% rating it insufficient or non-existent.

- Like their university counterparts, college faculty indicated instrumentation in the $10,000 and $50,000 range to be the first priority for more than half (54%) of the departments. The second highest priority was for equipment under $10,000 (25%), unlike universities where this range was first choice for only one in ten.

- To meet the aggregate capital investment for the three most needed individual items of instrumentation at the 50 colleges will require approximately $35 million over the next five years.

DETAILS :

In addition to providing information on specific items of scientific equipment and on 1984-85 expenditures, science faculty at the 50 liberal arts colleges were asked to respond to several opinion/evaluation items. As were the university faculty in the NSF study, the college faculty were requested to rate the overall adequacy of their department's instrumentation to research needs, the adequacy of technical support services for equipment, and the area of top priority if additional federal funding were available (as categorized by equipment price ranges). This final section of this chapter will present these responses, and will detail the monetary requirements for equipment rated necessary to meet both immediate and future needs.

Because teaching per se is so central a function at the undergraduate stage, science faculty at the 50 colleges of the liberal arts and sciences were requested to rate the adequacy of their scientific equipment and instrumentation specifically for teaching needs, as well as for those of research. These results with respect to teaching are presented in Table III-35. (Unfortunately, no comparable data are available for the research university environment since this item was not part of tne NSF study.)

Overall, slightly less than one-third (30%) of all reporting departments at the 50 colleges indicated their equipment was "excellent" for teaching purposes. However, only half as many (15%) indicated it was "inadequate". The remainder (55%) rated it "adequate".

These ratings exhibited significant variation by discipline, however. The generally more expensive, newer and more state of the art equipment in chemistry was rated excellent for teaching purposes in nearly half of the departments (47%), as was geology's (48%). Chemistry reported a lower than average frequency of inadequacy (11%), but geology's rating was about average (16%). Biology faculty reported excellent ratings of equipment for teaching purposes slightly more than one-third of the time (35%), and only 8% said inadequate.

Mathematics and physics/astronomy indicate the lowest frequency of excellent instrumentation for teaching purposes, each reporting this rating in only 13% of the departments. This frequency is less than half of the overall average, and below one-third of the highest proportion of excellent ratings found in chemistry and geology. Mathematics reported the most frequent rating of inadequacy among the disciplines (29%). The bulk of the physics departments (71%) rated their instrumentation adequate to teaching needs.

The adequacy of current scientific equipment for research, however, was not so highly rated. Nevertheless, ratings were somewhat higher than research university norms. In responding to this item, faculty were requested to differentiate between equipment available for research to tenured faculty, and that available to untenured faculty. As was true in universities, ratings of the adequacy of current equipment for research conducted by untenured faculty was below that for their tenured counterparts. Once again, physics and astronomy appear to report especially critical conditions on this item. These data are detailed in Table III-36. The following is a summary of all responses, with comparison to those at research universities:

Tenured Faculty						Untenured Faculty					
Excellent		Adequate		Insufficient		Excellent		Adequate		Insufficient	
Cols	Univ	Cols	Univ	Cols	Univ	Cols	Univ	Cols	Univ	Cols	Univ
20%	11%	47%	53%	32%	36%	19%	10%	44%	47%	37%	43%

These data may indicate somewhat less of a distinction in the quality of available equipment drawn between tenured and untenured faculty at the 50 colleges than appears to be drawn between these these two groups in the research university environment. However, this college-university difference is not great.

Even more than was true of the ratings of instrumentation adequacy for teaching, the ratings of its adequacy for research were most different from the college norms in physics and astronomy. These disciplines indicated excellent research equipment for tenured faculty in only 5% of the departments, and in only 10% for those untenured. It was rated insufficient in exactly half of the colleges responding (for tenured faculty) and in more than half (54%) for those untenured. Once again, these data appear to corroborate other results of this survey and strengthen the conclusion that special attention is required to address the instrumentation needs in physics and astronomy at the undergraduate level.

The response from college science faculty concerning the condition of technical support services (machine shop, electronics shop, local maintenance personnel) was very nearly equal to that of their research university counterparts (Table III-37 for details) :

Excellent		Adequate		Insufficient		Non-existent	
Col	Univ	Col	Univ	Col	Univ	Col	Univ
11%	11%	46%	39%	32%	36%	10%	13%

Both the college and the university faculty thus rated these functions either insufficient or non-existent in just under one-half of the departments.

Future Priorities and Funding Needs

The data so far paint a picture of scientific equipment and instrumentation at the undergraduate level in these 50 colleges which shows substantial quantity, sophistication and quality, as well as certain inadequacies and needs. In the attempt to characterize and quantify those needs, the science faculty at the 50 liberal arts colleges were requested to specify areas of highest priority, and to specify three instrument systems in the $10,000 to $1,000,000 range "most needed at this time", the three most needed in the next five years, and the estimated purchase costs for these systems in current dollars (1986).

Table III-38 details the response of the college science faculty when asked to indicate the one type of instrumentation (characterized chiefly by purchase price) "most beneficial to investigators in your department" if "greater

funding of research equipment were possible". While reasonably similar to the response from the research university environment, there were also some important differences:

Large Scale $1,000,000 +		Shared-access $50,000 - $1M		$10,000 - $50,000		Indiv. P.I. Labs less $10,000		Other	
Col	Univ	Col	Univ	Col	Univ	Col	Univ	Col	Univ
1%	2%	18%	26%	54%	61%	25%	10%	2%	1%

Neither the college nor the university faculty indicated large-scale regional and national instrumentation as a priority for new funding, and neither indicated any "other" types of equipment highly desirable. Both groups gave highest priority to equipment in the $10,000 to $50,000 range. However, this type of instrumentation was rated a somewhat lower priority (as was equipment in the $50,000 to $1,000,000 range) at colleges than at universities. The remaining category, "general enhancement of equipment and supplies in the laboratories of individual principal investigators, typically items under $10,000" was the first priority of one-quarter of the college science departments, but only one in ten faculty in the research universities.

Following this general prioritization of new equipment needs, science faculty at the 50 liberal arts colleges were asked to specify the three instrument systems most needed immediately, and the three most needed in the next five years. Table III-39 details the aggregate capital investment by discipline which these needs will require. As might be predicted, the responses to immediate and future needs elicited a high degree of overlap. This is evidenced by nearly identical total monetary investments required in current and near-future equipment stock for undergraduate science. Each of these totals is approximately $35 million, or just under three-quarters of a million dollars per institution over the next five years. This figure equates approximately to:

- 140,000 per institution per year
- $140,000 per science department over the next five years
- $28,000 per science department per year

While the aggregate total is formidable, this last ratio makes the task appear somewhat more easily accomplished.

End Notes -- Chapter III
Scientific Equipment and Instrumentation

[1] "Towards a National Policy for Undergraduate Science Education: with the Recommendations of the National Higher Education Associations' Task Force", The American Council on Education, Washington, D.C., 20036-1193, 1985.

[2] "Report of the NSB Task Committee on Undergraduate Science and Engineering Education to the National Science Board", NSB-86-100, The National Science Board, Washington, D.C., 1986.

[3] "Academic Research Equipment in Selected Science/Engineering Fields, 1982 - 83", The National Science Foundation, Washington, D.C., 1985.

[4] As in other sections of this report, "Other Sciences" contains data on departments of computer science (when separate from departments of mathematics), some engineering, environmental sciences, bio-psychology, etc.

[5] These proportions differ somewhat from those reported in Table III-32 because the data in the textual table can be based only on instruments for which age is known, whereas Table III-32 presents funding sources for all reported equipment, including approximately 12% for which age is unknown.

Chapter III -- Appendix A

Methodology and Caveats

Method

During 1985-86, a survey was mailed to each of the science departments at each of the 50 liberal arts colleges requesting data concerning annual expenditures for scientific equipment, sources for this funding, current and future priorities for equipment, and a variety of key data on four "most important" pieces of equipment currently in use. Thus, the population studied here is, in some cases, science departments at these institutions, and in other cases, the instrument systems which they detailed.

In order to provide some comparability to existing data, certain relevant items from the 1982 and 1983 survey instruments employed in the NSF-commissioned study were incorporated with other college-specific items. Of the 50 colleges surveyed, 41 (82%) provided data on one or more departments. Typically, when an institution provided data on one science department, all science departments' data were present. In the end, data were obtained from 37 departments of biology, 37 of chemistry, 24 of geology, 31 of mathematics, 45 of physics (and astronomy), and 23 "Other Sciences"4, and on 667 individual instrument systems.

Caveats :

1. As all data based on a sample, these data have some error. However, the response rate was fairly high and appeared to represent a good cross-section of the 50 institutions as measured by the proportion of the various science departments at these schools. Data presented here are estimates for the aggregate of all 50 institutions adjusted for sampling wherever appropriate (e.g., total numbers of instrument systems, aggregate purchase, acquisition and replacements costs, ratios per FTE student and faculty, etc.)

2. Comparisons with the 1985 NSF data:

   a. The science departments studied here are chiefly ones of the basic sciences. Therefore, they contain little data from departments of applied sciences. The tabular data here present some sub-totals for "Biological Sciences" and "Physical Sciences". However, bottom-line results are not highly comparable.

   b. The NSF-commissioned study sampled instruments from a known inventory. Without such a priori knowledge, this study had to rely on data for four "very important" instruments per department. It was hoped that by requesting data on more than one instrument per department, a reasonable cross-section of the current college stock might be obtained.

It is not clear that this attempt was entirely successful. For example, the NSF study found 20% of all instrument systems reported to be "no longer in research use" and "in effect, obsolete." Much of the aggregate data presented in the NSF report therefore contains the profiles of these instruments as well as the 80% "in research use". The data on the 50 colleges surveyed unavoidably contain only data on in-use systems. This methodological artifact likely biases the 50 colleges' data for instruments more state-of-the art, in better working condition and, perhaps, younger or more expensive than the norm.

c. The NSF study was limited consciously to systems whose original purchase cost was between $10,000 and $1,000,000. This initial limitation was consciously not placed on the 50 college study because, lacking a priori knowledge, (i) it was desirable to obtain first-pass data which were as unbiased and complete as possible, (ii) it was not certain what percentage of the current college stock would be excluded (perhaps a very high proportion), and (iii) because the analysis could always be limited later to the NSF price range if desired and if permitted by the data set.

The one million dollar upper bound was not a problem in the college data. The original purchase price of the most expensive system reported was $320,000. However, 30% of the colleges' systems were priced below $10,000. Most tables prepared for this chapter present both the complete data for all equipment reported at the colleges, and, in parallel form, data restricted to instrument systems within the NSF price range. These tables are presented for comparability to data on university and professional school scientific equipment subject to the caveats above.

c. Aggregate cost figures here are affected by general inflation in instrument costs for those systems purchased since the years of the NSF study.

Table III-1

Total amounts of academic research instrument systems and aggregate capital investment, all equipment regardless of purcahse price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Number and % of Instrument Systems		Aggregate Purchase Price		Mean Purchase Price per Instrument
	N	%	$ (000)	%	$ (000)
Biology	170	21.1%	$5,226	19.7%	$31
Chemistry	188	23.3%	$8,102	30.5%	$43
Geology	112	13.9%	$3,047	11.5%	$27
Mathematics	56	6.9%	$1,116	4.2%	$20
Astr. & Physics	196	24.3%	$5,924	22.3%	$30
Other sciences (3)	84	10.5%	$3,163	11.9%	$37
Total, all sciences	806	100.0%	$26,579	100.0%	$33
Fields in Aggregate					
Biological sciences	170	21.1%	$5,226	19.7%	$31
Physical sciences	495	61.5%	$17,074	64.2%	$34
All basic sciences (4)	722	89.5%	$23,416	88.1%	$32

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems reported regardless of original purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-2

Total amounts of academic research instrument systems and aggregate capital investment, equipment in the $10,000 to $1,000,000 range, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Number and % of Instrument Systems		Aggregate Purchase Price		Mean Purchase Price per Instrument
	N	%	$ (000)	%	$ (000)
Biology	131	23.3%	$4,924	19.8%	$38
Chemistry	160	28.5%	$7,793	31.3%	$49
Geology	66	11.8%	$2,752	11.0%	$42
Mathematics	21	3.8%	$965	3.9%	$46
Astr. & Physics	129	23.0%	$5,505	22.1%	$43
Other sciences (3)	55	9.8%	$2,982	12.0%	$54
Total, all sciences	562	100.0%	$24,922	100.0%	$44
Fields in Aggregate					
Biological sciences	131	23.3%	$4,924	19.8%	$38
Physical sciences	355	63.3%	$16,050	64.4%	$45
All basic sciences (4)	507	90.3%	$21,940	88.0%	$43

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-3

Indices of Equipment-Extensiveness: All instruments regardless of purchase cost,
by discipline and fields in aggregate,
at the 50 liberal arts colleges, 1985-86

Discipline	Number, Aggregate Purchase Price, All Systems		Means per Institution		Means per Tenure-Track FTE		Means per Prospective Major		Means per Senior Major	
	N	$ (000)	N	$ (000)	N	$ (000)	N	$ (000)	N	$ (000)
Biology	170	$5,226	3.41	$105	.48	$15	.09	$3	.10	$3
Chemistry	198	$8,102	3.75	$162	.57	$25	.29	$13	.23	$10
Geology	112	$3,047	2.23	$61	.86	$24	1.23	$33	.33	$9
Mathematics	56	$1,116	1.12	$22	.16	$3	.07	$1	.07	$1
Physics & Astr.	196	$5,924	3.92	$118	.77	$23	.48	$14	.49	$15
Other sciences (3)	84	$3,163	1.69	$63	.76	$28	.03	$1	.06	$2
Total, all sciences	806	$26,579	16.12	$532	.53	$17	.11	$4	.15	$5
Fields in Aggregate										
Biological sciences	170	$5,226	3.41	$105	.48	$15	.09	$3	.10	$3
Physical sciences	495	$17,074	9.91	$341	.70	$24	.43	$15	.32	$11
All basic sciences (4)	722	$23,416	14.43	$468	.51	$16	.18	$6	.18	$6

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems regardless of purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-4

Indices of Equipment-Extensiveness: Instruments with purchase cost between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Number, Aggregate Purchase Price, All Systems		Means per Institution		Means per Tenure-Track FTE		Means per Prospective Major		Means per Senior Major	
	N	$ (000)	N	$ (000)	N	$ (000)	N	$ (000)	N	$ (000)
Biology	131	$4,924	2.61	$98	.37	$14	.07	$2	.08	$3
Chemistry	160	$7,793	3.20	$156	.49	$24	.25	$12	.20	$10
Geology	66	$2,752	1.32	$55	.51	$21	.73	$30	.20	$8
Mathematics	21	$965	.42	$19	.06	$3	.03	$1	.03	$1
Physics & Astr.	129	$5,505	2.58	$110	.51	$22	.32	$13	.32	$14
Other sciences (3)	55	$2,982	1.10	$60	.49	$27	.02	$1	.04	$2
Total, all sciences	562	$24,922	11.24	$498	.37	$16	.08	$3	.10	$5
Fields in Aggregate										
Biological sciences	131	$4,924	2.61	$98	.37	$14	.07	$2	.08	$3
Physical sciences	355	$16,050	7.11	$321	.50	$23	.31	$14	.23	$10
All basic sciences (4)	507	$21,940	10.14	$439	.36	$15	.13	$6	.13	$5

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-5

Distribution of academic research instrument systems by original purchase price categories, all systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Total N, % of Instr. Systems		Less than $10,000		$10,000 - $24,999		$25,000 - $74,999		$75,000 - $1,000,000	
	N	% of Total N	N	%	N	%	N	%	N	%
Biology	170	21.1%	37	21.8%	63	37.0%	52	30.3%	19	10.9%
Chemistry	188	23.3%	24	13.0%	66	35.1%	67	35.9%	30	16.0%
Geology	112	13.9%	44	39.7%	29	25.6%	31	28.2%	7	6.4%
Mathematics	56	6.9%	34	61.5%	11	20.5%	9	15.4%	1	2.6%
Physics & Astr.	196	24.3%	64	32.8%	62	31.4%	50	25.5%	20	10.2%
Other sciences (3)	84	10.5%	29	33.9%	27	32.2%	11	13.6%	17	20.3%
Total, all sciences	806	100.0%	233	29.0%	258	32.0%	220	27.4%	94	11.7%
Fields in Aggregate										
Biological sciences	170	21.1%	37	21.8%	63	37.0%	52	30.3%	19	10.9%
Physical sciences	495	61.5%	133	26.9%	156	31.5%	149	30.1%	57	11.6%
All basic sciences (4)	722	89.5%	205	28.4%	231	31.9%	209	29.0%	77	10.7%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems reported regardless of purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-6

Distribution of academic research instrument systems aggregate purchase costs by original purchase price categories, all instrument systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Aggregate Purchase $		Less than $10,000		$10,000 - $24,999		$25,000 - $74,999		$75,000 - $1,000,000	
	$ (000)	% of Total $	$ (000)	%	$ (000)	%	$ (000)	%	$ (000)	%
Biology	$5,226	19.7%	$206	3.9%	$1,018	19.5%	$2,140	41.0%	$1,861	35.6%
Chemistry	$8,1[illegible]2	30.5%	$159	2.0%	$1,105	13.6%	$2,671	33.0%	$4,167	51.4%
Geology	$3,047	11.5%	$242	8.0%	$463	15.2%	$1,435	47.1%	$908	29.8%
Mathematics	$1,116	4.2%	$132	11.8%	$184	16.5%	$371	33.2%	$430	38.5%
Physics & Astr.	$5,924	22.3%	$313	5.3%	$981	16.6%	$1,730	29.2%	$2,901	49.0%
Other sciences (3)	$3,163	11.9%	$123	3.9%	$425	13.4%	$453	14.3%	$2,162	68.3%
Total, all sciences	$26,579	100.0%	$1,175	4.4%	$4,175	15.7%	$8,801	33.1%	$12,428	46.8%
Fields in Aggregate										
Biological sciences	$5,226	19.7%	$206	3.9%	$1,018	19.5%	$2,140	41.0%	$1,861	35.6%
Physical sciences	$17,074	64.2%	$713	4.2%	$2,548	14.9%	$5,836	34.2%	$7,976	46.7%
All basic sciences (4)	$23,416	88.1%	$1,052	4.5%	$3,750	16.0%	$8,348	35.6%	$10,266	43.8%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems reported regardless of purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-7

Distribution of academic research instrument systems by original purchase price categories, systems between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Total N and % of Instrument Systems		$10,000 - $24,999		$25,000 - $74,999		$75,000 - $1,000,000	
	N	% of Total N	N	%	N	%	N	%
Biology	131	23.3%	62	47.3%	51	38.7%	18	14.0%
Chemistry	160	28.5%	65	40.4%	66	41.2%	29	18.4%
Geology	66	11.8%	28	42.6%	31	46.8%	7	10.6%
Mathematics	21	3.8%	11	53.3%	8	40.0%	1	6.7%
Physics & Astr.	129	23.0%	60	46.7%	49	38.0%	20	15.2%
Other sciences (3)	55	9.8%	27	48.7%	11	20.5%	17	30.8%
Total, all sciences	562	100.0%	253	45.0%	216	38.5%	93	16.5%
Fields in Aggregate								
Biological sciences	131	23.3%	62	47.3%	51	38.7%	18	14.0%
Physical sciences	355	63.3%	153	43.1%	146	41.1%	56	15.8%
All basic sciences (4)	507	90.3%	226	44.6%	205	40.4%	76	15.0%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-8

Distribution of academic research instrument systems aggregate purchase costs by original purchase price categories, systems between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Aggregate Purchase $		$10,000 - $24,999		$25,000 - $74,999		$75,000 - $1,000,000	
	$ (000)	% of Total $	$ (000)	%	$ (000)	%	$ (000)	%
Biology	$4,924	19.8%	$999	20.3%	$2,100	42.6%	$1,826	37.1%
Chemistry	$7,793	31.3%	$1,084	13.9%	$2,621	33.6%	$4,088	52.5%
Geology	$2,752	11.0%	$454	16.5%	$1,407	51.1%	$891	32.4%
Mathematics	$965	3.9%	$180	18.7%	$364	37.7%	$421	43.6%
Physics & Astr.	$5,505	22.1%	$962	17.5%	$1,698	30.8%	$2,846	51.7%
Other sciences (3)	$2,982	12.0%	$417	14.0%	$445	14.9%	$2,121	71.1%
Total, all sciences	$24,922	100.0%	$4,096	16.4%	$8,634	34.6%	$12,193	48.9%
Fields in Aggregate								
Biological sciences	$4,924	19.8%	$999	20.3%	$2,100	42.6%	$1,826	37.1%
Physical sciences	$16,050	64.4%	$2,500	15.6%	$5,726	35.7%	$7,825	48.8%
All basic sciences (4)	$21,940	88.0%	$3,679	16.8%	$8,189	37.3%	$10,072	45.9%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-9

Median age of in-use academic research equipment, by technical capability, all systems regardless of initial purchase costs, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	All Systems	State of the Art	Non-State of the Art
Biology	7	3	12
Chemistry	6	3	8
Geology	8	4	18
Mathematics	3	2.5	3
Physics & Astr.	7	2	12
Other sciences (2)	3	3	4
Total, all sciences	5	3	9
Fields in Aggregate			
Biological sciences	7	3	12
Physical sciences	7	3	9
All basic sciences (3)	6	3	9

(1) Based on data for all instrument systems reported regardless of purchase cost, 41 out of 50 colleges reporting.

(2) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

(4) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-10

Median age of in-use academic research equipment, by technical capability,
all systems with purchase price between $10,000 and $1,000,000,
by discipline and fields in aggregate,
at the 50 liberal arts colleges, 1985-86

Discipline	All Systems	State of the Art	Non-State of the Art
Biology	6	3	11
Chemistry	5	3	8
Geology	8.5	4	18.5
Mathematics	3	2	3.5
Physics & Astr.	6.5	2	12
Other sciences (2)	3	3	4
Total, all sciences	5	3	9
Fields in Aggregate			
Biological sciences	6	3	11
Physical sciences	5.5	3	9
All basic sciences (3)	5	3	10

(1) Based on data for all instrument systems reported with original purchase price between $10,000 and $1,000,000, 41 out of 50 colleges reporting.

(2) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

(4) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-11

Distribution of academic research instrument systems by current age (years since purchase), all systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Total N and % of Instr. Systems		1 to 5 Years		6 to 10 Years		Over 10 Years	
	N	% of Total N	N	%	N	%	N	%
Biology	170	21.1%	72	42.0%	30	17.6%	69	40.3%
Chemistry	188	23.3%	94	50.4%	63	33.6%	30	16.0%
Geology	112	13.9%	52	46.2%	16	14.1%	44	39.7%
Mathematics	56	6.9%	49	87.2%	7	12.8%	0	.0
Physics & Astr.	196	24.3%	90	46.0%	29	14.6%	77	39.4%
Other sciences (3)	84	10.5%	57	67.8%	10	11.9%	17	20.3%
Total, all sciences	806	100.0%	414	51.3%	155	19.2%	238	29.5%
Fields in Aggregate								
Biological sciences	170	21.1%	72	42.0%	30	17.6%	69	40.3%
Physical sciences	495	61.5%	236	47.7%	107	21.7%	152	30.6%
All basic sciences (4)	722	89.5%	357	49.4%	145	20.0%	220	30.6%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems reported regardless of purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

(5) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-12

Distribution of academic research instrument systems aggregate purchase costs by current age (years since purchase), all systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Aggregate Purchase $		1 to 5 Years		6 to 10 Years		Over 10 Years	
	$ (000)	% of Total $	$ (000)	%	$ (000)	%	$ (000)	%
Biology	$5,226	19.7%	$2,547	48.7%	$764	14.6%	$1,915	36.6%
Chemistry	$8,102	30.5%	$5,630	69.5%	$1,856	22.9%	$616	7.6%
Geology	$3,047	11.5%	$1,525	50.0%	$224	7.4%	$1,298	42.6%
Mathematics	$1,116	4.2%	$1,093	98.0%	$23	2.0%	$0	.0
Physics & Astr.	$5,924	22.3%	$2,959	49.9%	$574	9.7%	$2,391	40.4%
Other sciences (3)	$3,163	11.9%	$2,825	89.3%	$194	6.1%	$144	4.5%
Total, all sciences	$26,579	100.0%	$16,580	62.4%	$3,635	13.7%	$6,364	23.9%
Fields in Aggregate								
Biological sciences	$5,226	19.7%	$2,547	48.7%	$764	14.6%	$1,915	36.6%
Physical sciences	$17,074	64.2%	$10,114	59.2%	$2,655	15.5%	$4,305	25.2%
All basic sciences (4)	$23,416	88.1%	$13,754	58.7%	$3,441	14.7%	$6,220	26.6%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems reported regardless of purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

(5) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-13

Distribution of academic research instrument systems by current age (years since purchase), systems between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Total N and % of Instr. Systems		1 to 5 Years		6 to 10 Years		Over 10 Years	
	N	% of Total N	N	%	N	%	N	%
Biology	131	23.3%	58	44.1%	25	19.4%	48	36.6%
Chemistry	160	28.5%	87	54.4%	53	33.3%	20	12.3%
Geology	66	11.8%	29	44.7%	6	8.5%	31	46.8%
Mathematics	21	3.8%	21	100.0%	0	.0	0	.0
Physics & Astr.	129	23.0%	62	47.8%	15	12.0%	52	40.2%
Other sciences (3)	55	9.8%	45	82.1%	6	10.3%	4	7.7%
Total, all sciences	562	100.0%	302	53.8%	105	18.8%	155	27.5%
Fields in Aggregate								
Biological sciences	131	23.3%	58	44.1%	25	19.4%	48	36.6%
Physical sciences	355	63.3%	178	50.2%	74	20.9%	103	28.9%
All basic sciences (4)	507	90.3%	257	50.7%	100	19.7%	150	29.6%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

(5) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-14

Distribution of academic research instrument systems aggregate purchase costs by current age (years since purchase), systems between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Aggregate Purchase $		1 to 5 Years		6 to 10 Years		Over 10 Years	
	$ (000)	% of Total $	$ (000)	%	$ (000)	%	$ (000)	%
Biology	$4,924	19.8%	$2,417	49.1%	$715	14.5%	$1,793	36.4%
Chemistry	$7,793	31.3%	$5,485	70.4%	$1,762	22.6%	$546	7.0%
Geology	$2,752	11.0%	$1,368	49.7%	$173	6.3%	$1,210	44.0%
Mathematics	$965	3.9%	$965	100.0%	$0	.0	$0	.0
Physics & Astr.	$5,505	22.1%	$2,786	50.6%	$483	8.8%	$2,237	40.6%
Other sciences (3)	$2,982	12.0%	$2,725	91.4%	$166	5.6%	$91	3.1%
Total, all sciences	$24,922	100.0%	$15,747	63.2%	$3,299	13.2%	$5,876	23.6%
Fields in Aggregate								
Biological sciences	$4,924	19.8%	$2,417	49.1%	$715	14.5%	$1,793	36.4%
Physical sciences	$16,050	64.4%	$9,639	60.1%	$2,418	15.1%	$3,993	24.9%
All basic sciences (4)	$21,940	88.0%	$13,022	59.4%	$3,133	14.3%	$5,785	26.4%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

(5) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-15

Distribution of academic research instrument systems by technical capability, all systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Total N and % of Instr. Systems		State of the Art		Adequate		Inadequate	
	N	% of Total N	N	%	N	%	N	%
Biology	170	21.1%	69	40.3%	86	50.4%	16	9.2%
Chemistry	188	23.3%	82	43.5%	89	47.3%	17	9.2%
Geology	112	13.9%	49	43.6%	46	41.0%	17	15.4%
Mathematics	56	6.9%	17	30.8%	31	56.4%	7	12.8%
Physics & Astr.	196	24.3%	53	27.0%	122	62.0%	21	10.9%
Other sciences (3)	84	10.5%	36	42.4%	44	52.5%	4	5.1%
Total, all sciences	806	100.0%	305	37.8%	418	51.9%	83	10.3%
Fields in Aggregate								
Biological sciences	170	21.1%	69	40.3%	86	50.4%	16	9.2%
Physical sciences	495	61.5%	183	37.0%	256	51.7%	56	11.3%
All basic sciences (4)	722	89.5%	269	37.3%	374	51.8%	79	10.9%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems reported regardless of purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-16

Distribution of academic research instrument systems aggregate purchase costs by technical capability, all systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Aggregate Purchase $		State of the Art		Adequate		Inadequate	
	$ (000)	% of Total $	$ (000)	%	$ (000)	%	$ (000)	%
Biology	$5,226	19.7%	$2,310	44.2%	$2,393	45.8%	$522	10.0%
Chemistry	$8,102	30.5%	$5,149	63.6%	$2,608	32.2%	$345	4.3%
Geology	$3,047	11.5%	$1,295	42.5%	$1,421	46.6%	$332	10.9%
Mathematics	$1,116	4.2%	$367	32.9%	$723	64.8%	$26	2.3%
Physics & Astr.	$5,924	22.3%	$2,453	41.4%	$3,075	51.9%	$396	6.7%
Other sciences	$3,163	11.9%	$1,770	56.0%	$1,271	40.2%	$122	3.9%
Total, all sciences	$26,579	100.0%	$13,345	50.2%	$11,492	43.2%	$1,742	6.6%
Fields in Aggregate								
Biological sciences	$5,226	19.7%	$2,310	44.2%	$2,393	45.8%	$522	10.0%
Physical sciences	$17,074	64.2%	$8,897	52.1%	$7,104	41.6%	$1,072	6.3%
All basic sciences (4)	$23,416	88.1%	$11,575	49.4%	$10,221	43.6%	$1,620	6.9%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems reported regardless of purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-17

Distribution of academic research instrument systems by technical capability, systems between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Total N and % of Instr. Systems		State of the Art		Adequate		Inadequate	
	N	% of Total N	N	%	N	%	N	%
Biology	131	23.3%	56	43.0%	63	48.4%	11	8.6%
Chemistry	160	28.5%	79	49.1%	70	43.9%	11	7.0%
Geology	66	11.8%	29	44.7%	27	40.4%	10	14.9%
Mathematics	21	3.8%	10	46.7%	11	53.3%	0	.0
Physics & Astr.	129	23.0%	44	33.7%	72	55.4%	14	10.9%
Other sciences (3)	55	9.8%	29	53.8%	22	41.0%	3	5.1%
Total, all sciences	562	100.0%	247	44.0%	265	47.3%	49	8.8%
Fields in Aggregate								
Biological sciences	131	23.3%	56	43.0%	63	48.4%	11	8.6%
Physical sciences	355	63.3%	152	42.7%	169	47.4%	35	9.9%
All basic sciences (4)	507	90.3%	218	42.9%	243	47.9%	46	9.1%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-18

Distribution of academic research instrument systems aggregate purchase costs, by technical capability, systems between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Aggregate Purchase $		State of the Art		Adequate		Inadequate	
	$ (000)	% of Total $	$ (000)	%	$ (000)	%	$ (000)	%
Biology	$4,924	19.8%	$2,187	44.4%	$2,244	45.6%	$493	10.0%
Chemistry	$7,793	31.3%	$5,039	64.7%	$2,445	31.4%	$308	4.0%
Geology	$2,752	11.0%	$1,159	42.1%	$1,306	47.5%	$287	10.4%
Mathematics	$965	3.9%	$334	34.6%	$632	65.4%	$0	.0
Physics & Astr.	$5,505	22.1%	$2,357	42.8%	$2,800	50.9%	$348	6.3%
Other sciences (3)	$2,982	12.0%	$1,710	57.3%	$1,156	38.8%	$116	3.9%
Total, all sciences	$24,922	100.0%	$12,786	51.3%	$10,583	42.5%	$1,553	6.2%
Fields in Aggregate								
Biological sciences	$4,924	19.8%	$2,187	44.4%	$2,244	45.6%	$493	10.0%
Physical sciences	$16,050	64.4%	$8,554	53.3%	$6,552	40.8%	$944	5.9%
All basic sciences (4)	$21,940	88.0%	$11,075	50.5%	$9,427	43.0%	$1,437	6.6%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-19

Numbers and percentages of academic research equipment, distributed by age and technical capability, all systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Age in Years		Total	State of the Art		Adequate		Inadequate	
		N	N	%	N	%	N	%
1	N	26	24	94%	1	6%		
	%	3%	8%		0%			
2	N	141	102	73%	34	24%	4	3%
	%	17%	33%		8%		5%	
3	N	115	57	49%	57	49%	1	1%
	%	14%	19%		14%		2%	
4	N	82	53	64%	28	34%	1	2%
	%	10%	17%		7%		2%	
5	N	51	20	39%	30	58%	1	3%
	%	6%	7%		7%		2%	
1-5 Yrs.	N	415	256	62%	151	36%	9	2%
	%	51%	84%		36%		10%	
6-10 Yrs.	N	155	33	21%	109	71%	13	8%
	%	19%	11%		26%		15%	
10 + Yrs.	N	236	17	7%	156	66%	63	27%
	%	29%	6%		38%		75%	
All Systems		806	306	38%	417	52%	84	10%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include estimation for those instruments for which either age, technical capability, or both, were not reported.

(2) Includes data for all instrument systems reported regardless of original purchase price.

(3) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-20

Numbers and percentages of academic research equipment, distributed by age and technical capability, all systems with purchase price between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Age in Years		Total	State of the Art		Adequate		Inadequate	
		N	N	%	N	%	N	%
1	N	21	20	93%	1	7%		
	%	4%	8%		1%			
2	N	104	85	82%	18	18%		
	%	18%	35%		7%			
3	N	73	42	58%	29	40%	1	2%
	%	13%	17%		11%		3%	
4	N	64	43	67%	20	30%	1	2%
	%	11%	18%		7%		3%	
5	N	39	18	46%	20	50%	1	4%
	%	7%	7%		7%		3%	
1-5 Yrs.	N	301	209	69%	88	29%	4	1%
	%	54%	85%		33%		9%	
6-10 Yrs.	N	106	22	21%	77	72%	7	7%
	%	19%	9%		29%		14%	
10 + Yrs.	N	154	15	10%	101	65%	38	25%
	%	27%	6%		38%		77%	
All Systems		562	247	44%	266	47%	49	9%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include estimation for those instruments for which either age, technical capability, or both, were not reported.

(2) Includes data for all and only instrument systems with original purchase price between $10,000 and $1,000,000.

(3) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-21

Distribution of academic research instrument systems by current working condition, all systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Total N and % of Instrument Systems		Excellent		Average - Adequate		Poor and Inoperable	
	N	% of Total N	N	%	N	%	N	%
Biology	170	21.1%	105	61.3%	49	28.6%	17	10.1%
Chemistry	188	23.3%	133	71.0%	40	21.4%	14	7.6%
Geology	112	13.9%	69	61.5%	27	24.4%	16	14.1%
Mathematics	56	6.9%	39	69.2%	14	25.6%	3	5.1%
Physics & Astr.	196	24.3%	122	62.0%	59	29.9%	16	8.0%
Other sciences (3)	84	10.5%	64	76.3%	19	22.0%	1	1.7%
Total, all sciences	806	100.0%	531	65.9%	208	25.8%	67	8.3%
Fields in Aggregate								
Biological sciences	170	21.1%	105	61.3%	49	28.6%	17	10.1%
Physical sciences	495	61.5%	324	65.3%	126	25.4%	46	9.2%
All basic sciences (4)	722	89.5%	467	64.7%	189	26.2%	66	9.1%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems reported regardless of purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-22

Distribution of academic research instrument systems aggregate purchase costs by current working condition, all systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Aggregate Purchase $		Excellent		Average - Adequate		Poor and Inoperable	
	$ (000)	% of Total $	$ (000)	%	$ (000)	%	$ (000)	%
Biology	$5,226	19.7%	$3,470	66.4%	$1,208	23.1%	$548	10.5%
Chemistry	$8,102	30.5%	$6,634	81.9%	$1,205	14.9%	$263	3.2%
Geology	$3,047	11.5%	$1,765	57.9%	$898	29.5%	$384	12.6%
Mathematics	$1,116	4.2%	$579	51.9%	$517	46.3%	$20	1.8%
Physics & Astr.	$5,924	22.3%	$4,286	72.3%	$1,293	21.8%	$345	5.8%
Other sciences (3)	$3,163	11.9%	$2,685	84.9%	$470	14.9%	$9	.3%
Total, all sciences	$26,579	100.0%	$19,419	73.1%	$5,591	21.0%	$1,569	5.9%
Fields in Aggregate								
Biological sciences	$5,226	19.7%	$3,470	66.4%	$1,208	23.1%	$548	10.5%
Physical sciences	$17,074	64.2%	$12,685	74.3%	$3,396	19.9%	$993	5.8%
All basic sciences (4)	$23,416	88.1%	$16,734	71.5%	$5,122	21.9%	$1,560	6.7%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all instrument systems reported regardless of purchase cost.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-23

Distribution of academic research instrument systems by current working condition, systems between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Total N and % of Instrument Systems		Excellent		Average - Adequate		Poor and Inoperable	
	N	% of Total N	N	%	N	%	N	%
Biology	131	23.3%	84	64.5%	32	24.7%	14	10.8%
Chemistry	160	28.5%	122	76.3%	31	19.3%	7	4.4%
Geology	66	11.8%	39	59.6%	18	27.7%	8	12.8%
Mathematics	21	3.8%	17	80.0%	4	20.0%	0	.0
Physics & Astr.	129	23.0%	80	62.0%	38	29.3%	11	8.7%
Other sciences (3)	55	9.8%	45	82.1%	10	17.9%	0	.0
Total, all sciences	562	100.0%	388	69.0%	133	23.8%	41	7.3%
Fields in Aggregate								
Biological sciences	131	23.3%	84	64.5%	32	24.7%	14	10.8%
Physical sciences	355	63.3%	242	68.0%	87	24.5%	27	7.5%
All basic sciences (4)	507	90.3%	343	67.6%	124	24.4%	41	8.0%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-24

Distribution of academic research instrument systems aggregate purchase costs by current working condition, systems between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Aggregate Purchase $		Excellent		Average - Adequate		Poor and Inoperable	
	$ (000)	% of Total $	$ (000)	%	$ (000)	%	$ (000)	%
Biology	$4,924	19.8%	$3,291	66.8%	$1,115	22.6%	$519	10.5%
Chemistry	$7,793	31.3%	$6,444	82.7%	$1,125	14.4%	$224	2.9%
Geology	$2,752	11.0%	$1,580	57.4%	$827	30.0%	$345	12.5%
Mathematics	$965	3.9%	$494	51.2%	$471	48.8%	$0	.0
Physics & Astr.	$5,505	22.1%	$4,026	73.1%	$1,164	21.1%	$315	5.7%
Other sciences (3)	$2,982	12.0%	$2,553	85.6%	$429	14.4%	$0	.0
Total, all sciences	$24,922	100.0%	$18,388	73.8%	$5,131	20.6%	$1,403	5.6%
Fields in Aggregate								
Biological sciences	$4,924	19.8%	$3,291	66.8%	$1,115	22.6%	$519	10.5%
Physical sciences	$16,050	64.4%	$12,050	75.1%	$3,116	19.4%	$884	5.5%
All basic sciences (4)	$21,940	88.0%	$15,835	72.2%	$4,702	21.4%	$1,403	6.4%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include adjustment for the 10% of instruments reported for which purchase price was unknown.

(2) Includes data for all and only instrument systems with purchase cost between $10,000 and $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-25

Numbers and percentages of academic research equipment, distributed by age and working condition, all systems regardless of purchase price, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Age in Years		Total N	Excellent N	Excellent %	Adequate N	Adequate %	Poor N	Poor %	Inoperable N	Inoperable %
1	N	26	26	100%						
	%	3%	5%							
2	N	141	132	94%	9	6%				
	%	17%	25%		4%					
3	N	115	102	89%	11	10%	1	1%		
	%	14%	19%		5%		3%			
4	N	82	78	95%	3	3%	1	2%		
	%	10%	15%		1%		3%			
5	N	51	36	69%	16	31%				
	%	6%	7%		8%					
1-5 Yrs.	N	415	374	90%	38	9%	3	1%		
	%	51%	70%		18%		6%			
6-10 Yrs.	N	155	87	56%	55	36%	11	7%	1	1%
	%	19%	16%		27%		24%		8%	
10 + Yrs.	N	236	71	30%	114	48%	34	14%	17	7%
	%	29%	13%		55%		71%		92%	
All Systems		806	532	66%	208	26%	48	6%	18	2%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include estimation for those instruments for which either age, current working condition, or both, were not reported.

(2) Includes data for all instrument systems reported regardless of original purchase price.

(3) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-26

Numbers and percentages of academic research equipment distributed by age and working condition, all systems with purchase price between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Age in Years		Total	Excellent		Adequate		Poor		Inoperable	
		N	N	%	N	%	N	%	N	%
1	N	21	21	100%						
	%	4%	5%							
2	N	104	97	93%	7	7%				
	%	18%	25%		5%					
3	N	73	64	88%	8	12%				
	%	13%	17%		6%					
4	N	64	63	98%	1	2%				
	%	11%	16%		1%					
5	N	39	29	75%	10	25%				
	%	7%	8%		7%					
1-5 Yrs.	N	301	275	91%	27	9%				
	%	54%	71%		20%					
6-10 Yrs.	N	106	60	57%	38	36%	8	8%		
	%	19%	16%		28%		29%			
10 + Yrs.	N	154	52	34%	70	45%	21	14%	11	7%
	%	27%	13%		52%		71%		100%	
All Systems		562	387	69%	135	24%	29	5%	11	2%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting, and include estimation for those instruments for which either age, current working condition, or both, were not reported.

(2) Includes data for all and only instrument systems with original purchase price between $10,000 and $1,000,000.

(3) Age is based on year of purchase. An instrument system purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-27

Dedication of academic research equipment to teaching and to research, by original purchase price, all systems regardless of initial purchase costs, by discipline and in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Less than $10,000		$10,000 - $24,999		$25,000 - $74,999		$75,000 or more		All Systems	
	% Teach	% Rsrch	% Teach	% Rsrch	% Teach	% Rsrch	% Teach	% Rsrch	% Teach	% Rsrch
Biology	61%	39%	40%	59%	55%	43%	69%	31%	52%	47%
Chemistry	77%	23%	59%	39%	48%	51%	41%	57%	54%	45%
Geology	60%	39%	50%	50%	59%	41%	38%	53%	56%	44%
Mathematics	56%	32%	77%	23%	69%	29%	**	**	63%	29%
Physics & Astr.	68%	28%	50%	50%	56%	39%	28%	68%	56%	42%
Other sciences (3)	57%	38%	69%	26%	74%	23%	67%	28%	65%	30%
Total, all sciences	63%	33%	53%	46%	55%	43%	48%	48%	56%	42%
Fields in Aggregate										
Bilogical sciences	61%	39%	40%	59%	55%	43%	69%	31%	52%	47%
Physical sciences	67%	31%	54%	45%	53%	45%	36%	60%	55%	43%
All basic sciences (4)	64%	33%	51%	48%	54%	44%	44%	53%	55%	43%

(1) Based on data for all systems reported regardless of original purchase price at the 50 colleges, based on a sample of 41 reporting.

(2) Differences between the sum of (percent teaching + percent research) and 100% "% other" usage (typically not specified).

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and physics & astronomy.

(5) ** = sample less than five instruments.

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Table III-28

Dedication of academic research equipment to teaching and to research, by age of the instrument, all systems regardless of initial purchase costs, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	1 - 5 Years		6 - 10 Years		10 + Years		All Systems	
	% Teach	% Rsrch	% Teach	% Rsrch	% Teach	% Rsrch	% Teach	% Rsrch
Biology	50%	49%	38%	60%	59%	41%	52%	47%
Chemistry	46%	52%	58%	42%	67%	33%	54%	45%
Geology	46%	53%	69%	31%	61%	38%	56%	44%
Mathematics	62%	30%	74%	18%	N/A	N/A	63%	29%
Physics & Astr.	42%	56%	59%	40%	70%	27%	56%	42%
Other sciences (3)	69%	26%	78%	22%	45%	49%	65%	30%
Total, all sciences	51%	46%	57%	41%	63%	35%	56%	42%
Fields in Aggregate								
Biological sciences	50%	49%	38%	60%	59%	41%	52%	47%
Physical sciences	45%	54%	59%	40%	66%	31%	55%	43%
All basic sciences (4)	48%	49%	56%	43%	64%	34%	55%	43%

(1) Based on data for all systems reported regardless of original purchase price at the 50 colleges, based on a sample of 41 reporting.

(2) Differences between the sum of (percent teaching + percent research) and 100% "% other" usage (typically not specified).

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and physics & astronomy.

(5) Age is based on year of purchase. An instrument purchased in 1986 is one year old; a system purchased in 1985 is two years old, etc.

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Table III-29

Dedication of academic research equipment to teaching and to research, by technical capability, all systems regardless of initial purchase costs, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	State of the Art		Adequate		Inadequate		All Systems	
	% Teach	% Rsrch	% Teach	% Rsrch	% Teach	% Rsrch	% Teach	% Rsrch
Biology	51%	48%	51%	48%	59%	41%	52%	47%
Chemistry	44%	55%	60%	38%	61%	37%	54%	45%
Geology	48%	50%	59%	41%	65%	35%	56%	44%
Mathematics	46%	41%	73%	23%	**	**	63%	29%
Physics & Astr.	35%	63%	63%	35%	61%	25%	56%	42%
Other sciences (3)	72%	28%	62%	28%	**	**	65%	30%
Total, all sciences	48%	50%	60%	37%	61%	34%	56%	42%
Fields in Aggregate								
Biological sciences	51%	48%	51%	48%	59%	41%	52%	47%
Physical sciences	43%	56%	61%	37%	62%	32%	55%	43%
All basic sciences (4)	45%	53%	59%	39%	61%	34%	55%	43%

(1) Based on data for all systems reported regardless of original purchase price at the 50 colleges, based on a sample of 41 reporting.

(2) Differences between the sum of (percent teaching + percent research) and 100% "% other" usage (typically not specified).

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and physics & astronomy.

(5) ** = sample less than five instruments.

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Table III-30

Dedication of academic research equipment to teaching and research, by current working condition, all systems regardless of initial purchase costs, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	Excellent		Adequate		Poor		All Systems	
	% Teach	% Rsrch	% Teach	% Rsrch	% Teach	% Rsrch	% Teach	% Rsrch
Biology	47%	51%	58%	41%	60%	40%	52%	47%
Chemistry	50%	49%	57%	41%	68%	31%	54%	45%
Geology	49%	50%	62%	38%	61%	39%	56%	44%
Mathematics	61%	30%	76%	18%	**	**	63%	29%
Physics & Astr.	46%	52%	67%	32%	91%	6%	56%	42%
Other sciences (3)	68%	27%	54%	37%	N/A	N/A	65%	30%
Total, all sciences	52%	46%	62%	36%	68%	31%	56%	42%
Fields in Aggregate								
Biological sciences	47%	51%	58%	41%	60%	40%	52%	47%
Physical sciences	48%	50%	63%	36%	74%	25%	55%	43%
All basic sciences (4)	49%	49%	63%	36%	68%	31%	55%	43%

(1) Based on data for all systems reported regardless of original purchase price at the 50 colleges, based on a sample of 41 reporting.

(2) Differences between the sum of (percent teaching + percent research) and 100% "% other" usage (typically not specified).

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and physics & astronomy.

(5) ** = sample less than five instruments.

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Table III-31

Aggregate annual expenditures on equipment, broken down into purchase and acquisition, maintenance and repair, operations, and other costs, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1984-85

Discipline	N of Depts	Total 1984-85 Expend. $ (000)	Mean $ per Dept	Mean $ per FTE Faculty	Purchase & acquist'n costs		Maintenance & repair costs		Operations costs		Other costs	
					$ (000)	%	$ (000)	%	$ (000)	%	$ (000)	%
Biology	45	$3,672	$81,382	$10,405	$2,816	76.7%	$578	15.7%	$278	7.6%	$1	.0
Chemistry	45	$3,294	$72,999	$10,070	$2,757	83.7%	$335	10.2%	$201	6.1%	$1	.0
Geology	29	$1,343	$45,880	$10,396	$1,141	84.9%	$135	10.1%	$67	5.0%	$0	.0
Math	38	$254	$6,709	$707	$219	86.3%	$23	9.0%	$12	4.7%	$0	.0
Physics & Astr.	55	$1,711	$31,179	$6,758	$1,469	85.9%	$128	7.5%	$111	6.5%	$3	.2%
Other science (2)	28	$1,814	$64,673	$16,326	$1,607	88.6%	$128	7.1%	$79	4.4%	$0	.0
Totals :	240	~$12,087	$50,313	$7,890	$10,009	82.8%	$1,326	11.0%	$748	6.2%	$4	.0
Fields in Aggregate												
Biological sciences	45	$3,672	$81,382	$10,405	$2,816	76.7%	$578	15.7%	$278	7.6%	$1	.0
Physical sciences	129	$6,348	$49,105	$8,948	$5,368	84.6%	$598	9.4%	$379	6.0%	$4	.1%
All basic sciences (3)	212	$10,273	$48,415	$7,230	$8,403	81.8%	$1,198	11.7%	$668	6.5%	$4	.0

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting.

(2) Other science = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-32

Aggregate annual expenditures on equipment, broken down into Federal, internal institutional, state, private non-profit, business and industry, and other sources of funds, by discipline and fields in aggregate at the 50 liberal arts colleges, 1984-85

Discipline	N of Depts	1984-85 Expend. $ (000)	Federal funds $ (000)	Federal funds %	Internal inst'l funds $ (000)	Internal inst'l funds %	State funds $ (000)	State funds %	Private non-profit funds $ (000)	Private non-profit funds %	Business & industry funds $ (000)	Business & industry funds %	Other funds $ (000)	Other funds %
Biology	45	$3,672	$356	9.7%	$1,566	42.6%	$0	.0	$978	26.6%	$95	2.6%	$677	18.4%
Chemistry	45	$3,294	$716	21.7%	$1,179	35.8%	$1	.0	$778	23.6%	$606	18.4%	$14	.4%
Geology	29	$1,343	$117	8.7%	$496	36.9%	$0	.0	$710	52.9%	$18	1.4%	$1	.1%
Math	38	$254	$1	.4%	$151	59.5%	$0	.0	$38	14.8%	$47	18.4%	$18	6.9%
Physics & Astr.	55	$1,711	$306	17.9%	$913	53.4%	$18	1.1%	$288	16.8%	$167	9.8%	$19	1.1%
Other sciences (2)	28	$1,814	$331	18.3%	$608	33.5%	$92	5.1%	$113	6.2%	$629	34.6%	$41	2.3%
Totals :	240	$12,087	$1,827	15.1%	$4,913	40.6%	$111	.9%	$2,904	24.0%	$1,562	12.9%	$770	6.4%
Fields in Aggregate														
Biological sciences	45	$3,672	$356	9.7%	$1,566	42.6%	$0	.0	$978	26.6%	$95	2.6%	$677	18.4%
Physical sciences	129	$6,348	$1,139	17.9%	$2,588	40.8%	$19	.3%	$1,776	28.0%	$791	12.5%	$34	.5%
All basic sciences (3)	212	$10,273	$1,496	18.3%	$4,305	33.5%	$19	5.1%	$2,791	6.2%	$933	34.6%	$729	2.3%

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting.

(2) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) All basic sciences = biology, chemistry, geology, mathematics, and astronomy and physics.

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Table III-33

Funding Sources : proportions of academic research equipment and aggregate purchase costs whose acquisition was supported by Federal, institutional, private and other sources, all systems, regardless of original purchase costs, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Discipline	% of Instruments Acquired With :				% of Aggregate Acquisition Costs			
	Federal	Inst'l	Private	Other	Federal	Inst'l	Private	Other
Biology	39%	68%	24%	5%	21%	47%	29%	3%
Chemistry	43%	55%	45%	19%	32%	24%	37%	7%
Geology	42%	72%	30%	6%	32%	30%	33%	5%
Mathematics	3%	78%	28%	0%	1%	84%	15%	0%
Physics & Astr.	38%	60%	36%	12%	33%	24%	24%	18%
Other sciences (2)	35%	68%	31%	21%	27%	40%	11%	21%
Total, all sciences	37%	64%	34%	12%	26%	39%	26%	9%
Fields in Aggregate								
Biological sciences	39%	68%	24%	5%	21%	47%	29%	3%
Physical sciences	41%	61%	38%	13%	32%	26%	32%	10%
All basic sciences (3)	38%	64%	34%	10%	25%	39%	29%	7%

(1) Based on data for all systems reported at 41 of the 50 colleges, regardless of purchase price.

(2) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) Basic sciences = biology, chemistry, geology, mathematics, and physics & astronomy.

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Table III-34

Funding Sources : proportions of academic research equipment and aggregate purchase costs whose acquisition was supported by Federal, institutional, private and other sources, all and only systems with purchase cost between $10,000 and $1,000,000, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1984-85

Discipline	% of Instruments Acquired With :				% of Aggregate Acquisition Costs			
	Federal	Inst'l	Private	Other	Federal	Inst'l	Private	Other
Biology	43%	63%	29%	5%	20%	46%	30%	3%
Chemistry	44%	54%	44%	19%	33%	25%	36%	7%
Geology	61%	67%	39%	7%	32%	28%	35%	6%
Mathematics	7%	100%	7%	0%	1%	96%	3%	0%
Physics & Astr.	44%	57%	42%	10%	33%	24%	26%	18%
Other sciences (2)	39%	66%	21%	34%	26%	41%	11%	23%
Total, all sciences	44%	61%	36%	13%	24%	44%	23%	9%
Fields in Aggregate								
Biological sciences	43%	63%	29%	5%	20%	46%	30%	3%
Physical sciences	47%	58%	42%	13%	33%	25%	32%	10%
All basic sciences (3)	44%	61%	37%	10%	24%	45%	25%	6%

(1) Based on data for all systems reported at 41 of the 50 colleges, regardless of purchase price.

(2) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) Basic sciences = biology, chemistry, geology, mathematics, and physics & astronomy.

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Table III-35

Assessment of equipment and instrumentation used for teaching,
by discipline and fields in aggregate,
at the 50 liberal arts colleges, 1985-86

	Assessment of Equipment & Instrumentation for Teaching							
	Excellent		Adequate		Insufficient		Totals	
Discipline	N	%	N	%	N	%	N	%
Biology	13	35.1%	21	56.8%	3	8.1%	37	19.4%
Chemistry	17	47.2%	15	41.7%	4	11.1%	36	18.8%
Geology	12	48.0%	9	36.0%	4	16.0%	25	13.1%
Math	3	12.5%	14	58.3%	7	29.2%	24	12.6%
Astr. & Physics	6	13.3%	32	71.1%	7	15.6%	45	23.6%
Other sciences (2)	6	25.0%	14	58.3%	4	16.7%	24	12.6%
Totals :	57	29.8%	105	55.0%	29	15.2%	191	100.0%
Fields in Aggregate								
Biological sciences	13	35.1%	21	56.8%	3	8.1%	37	19.4%
Physical sciences	35	33.0%	56	52.8%	15	14.2%	106	55.5%
All basic sciences (3)	51	30.5%	91	54.5%	25	15.0%	167	87.4%

(1) All statistics are based on unadjusted data from all reporting departments at 41 of the 50 colleges.

(2) Other science = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) All basic sciences = biology, chemistry, geology, mathematics, and physics and astronomy.

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Table III-36

Assessment of equipment and instrument systems used for research available to tenured and non-tenured faculty, by discipline and fields in aggregate, at the 50 liberal arts colleges, 1985-86

Assessment of Equipment & Instrument Systems for Research

Discipline	Tenured faculty						Non-tenured faculty					
	Excellent		Adequate		Insufficient		Excellent		Adequate		Insufficient	
	N	%	N	%	N	%	N	%	N	%	N	%
Biology	10	27.0%	18	48.6%	9	24.3%	8	21.6%	20	54.1%	9	24.3%
Chemistry	14	37.8%	15	40.5%	8	21.6%	9	25.0%	14	38.9%	13	36.1%
Geology	5	20.0%	12	48.0%	8	32.0%	4	19.0%	12	57.1%	5	23.8%
Math	4	20.0%	11	55.0%	5	25.0%	4	18.2%	9	40.9%	9	40.9%
Physics & Astr.	2	4.5%	20	45.5%	22	50.0%	4	10.3%	14	35.9%	21	53.8%
Other sciences (2)	3	13.0%	12	52.2%	8	34.8%	4	18.2%	9	40.9%	9	40.9%
Totals :	38	20.4%	88	47.3%	60	32.3%	33	18.6%	78	44.1%	66	37.3%
Fields in Aggregate												
Biological sciences	10	27.0%	18	48.6%	9	24.3%	8	21.6%	20	54.1%	9	24.3%
Physical sciences	21	19.8%	47	44.3%	38	35.8%	17	17.7%	40	41.7%	39	40.6%
All basic sciences (3)	35	21.5%	76	46.6%	52	31.9%	29	131.8%	69	313.6%	57	259.1%

(1) All statistics are based on unadjusted data for all reporting departments at 41 of the 50 colleges.

(2) Other science = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) All basic sciences = biology, chemistry, geology, mathematics, and physics and astronomy.

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Table III-37

Assessment of equipment and instrument systems support services,
by discipline and fields in aggregate,
at the 50 liberal arts colleges, 1985-86

	Assessment of Support Services							
	Excellent		Adequate		Insufficient		Nonexistent	
Discipline	N	%	N	%	N	%	N	%
Biology	2	5.4%	19	51.4%	11	29.7%	5	13.5%
Chemistry	4	10.8%	14	37.8%	14	37.8%	5	13.5%
Geology	0	.0	13	52.0%	12	48.0%	0	.0
Math	2	8.3%	14	58.3%	4	16.7%	4	16.7%
Physics & Astr.	6	13.3%	22	48.9%	14	31.1%	3	6.7%
Other sciences (2)	7	29.2%	7	29.2%	7	29.2%	3	12.5%
Totals :	21	10.9%	89	46.4%	62	32.3%	20	10.4%
Fields in Aggregate								
Biological sciences	2	5.4%	19	51.4%	11	29.7%	5	13.5%
Physical sciences	10	9.3%	49	45.8%	40	37.4%	8	7.5%
All basic sciences (3)	14	8.3%	82	48.8%	55	32.7%	17	15.9%

(1) All statistics are based on unadjusted data from all reporting departments at 41 of the 50 colleges.

(2) Other science = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) All basic sciences = biology, chemistry, geology, mathematics, and physics and astronomy

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Table III-38

Suggested areas for increased investment in research equipment,
by discipline and fields in aggregate,
at the 50 liberal arts colleges, 1985-86

	Suggested Areas for Increased Investment									
	1 *		2 *		3 *		4 *		5 *	
Discipline	N	%	N	%	N	%	N	%	N	%
Biology	0	.0	2	5.4%	26	70.3%	9	24.3%	0	.0
Chemistry	0	.0	7	18.9%	25	67.6%	5	13.5%	0	.0
Geology	0	.0	12	48.0%	7	28.0%	5	20.0%	0	.0
Math	1	5.3%	1	5.3%	8	42.1%	8	42.1%	1	5.3%
Physics & Astr.	1	2.3%	3	7.0%	23	53.5%	14	32.6%	2	4.7%
Other science (2)	0	.0	8	33.3%	10	41.7%	6	25.0%	0	.0
Totals :	2	1.1%	33	17.8%	99	53.5%	47	25.4%	3	1.6%
Fields in Aggregate										
Biological sciences	0	.0	2	5.4%	26	70.3%	9	24.3%	0	.0
Physical sciences	1	1.0%	22	21.0%	55	52.4%	24	22.9%	2	1.9%
All basic sciences (3)	2	1.2%	25	15.5%	89	55.3%	41	25.5%	3	1.9%

(1) All statistics are based on unadjusted data from all reporting departments at 41 of the 50 colleges.

(2) Other science = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(3) All basic sciences = biology, chemistry, geology, mathematics, and physics and astronomy.

1 * = Large-scale regional and national instrumentation facilities
2 * = Major shared-access instrument systems ($50,000 - $1,000,000)
3 * = Upgrading/expansion of equipment in the $10,000 to $50,000 range
4 * = General enhancement of equipment and supplies in labs of individual principal investigators (i.e., items generally less than $10,000)
5 * = Other

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Table III-39

Average and aggregate costs of immediate and projected equipment needs,
instruments between $10,000 and $1,000,000,
by discipline and fields in aggregate,
at the 50 liberal arts colleges, 1985-86

Discipline	Immediate Needs: Average, per Dept	Immediate Needs: Aggregate, All 50 Col's	Projected 5-Year Needs: Average, per Dept	Projected 5-Year Needs: Aggregate, All 50 Col's	N of Depts
Biology	$122,065	$5,507,811	$103,682	$4,678,334	45
Chemistry	$194,434	$8,773,241	$168,541	$7,604,899	45
Geology	$243,607	$7,129,961	$231,961	$6,789,102	29
Math	$114,167	$4,316,070	$148,692	$5,621,283	38
Physics & Astr.	$106,008	$5,817,512	$140,867	$7,730,506	55
Other sciences (3)	$113,409	$3,180,984	$104,950	$2,943,720	28
Totals :	$144,543	$34,725,579	$147,216	$35,367,844	240
Fields in Aggregate					
Biological sciences	$122,065	$5,507,811	$103,682	$4,678,334	45
Physical sciences	$168,028	$21,720,715	$171,152	$22,124,507	129
All basic sciences (4)	$148,658	$31,544,595	$152,803	$32,424,124	212

(1) All statistics are estimates of aggregate values for all 50 colleges, based on a sample of 41 reporting.

(2) Data are equipment purchase costs in current (1986) dollars for all and only instruments in the range of $10,000 to $1,000,000.

(3) Other sciences = pre-medical, engineering and all applied sciences, computer science, environmental sciences, psycho-biology, etc., but excludes psychology per se.

(4) All basic sciences = biology, chemistry, geology, mathematics, and physics and astronomy.

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Chapter IV

Physical Plant:
Facilities for Teaching and Research

The 1985 Report did not assess the physical plant's condition and adequacy for effective science teaching and scientific research. During the conference itself, physical plant issues were frequently discussed. Hence we present here the results of an initial survey of the buildings housing science departments.

Data are available from 39 institutions. The responses vary considerably in comprehensiveness and quality. This fact, along with the ~~comments~~ made on individual questionnaires, suggests to us that plant planning may not be sufficiently well integrated with planning in other areas of science education.

With regard to the physical plant, here are the highlights:

* Institutions average 3.9 building devoted in whole or in part to scientific activities.

* Over 40% of the total square footage is devoted to laboratories, both for teaching and research.

* Square footage per department and per faculty member varies widely.

* About 60% of the buildings are rated to be in either excellent or very good condition. However, 11% are rated to be only fair or poor.

* These buildings average 48 years in age.

* The effective age, that is the number of years since the last major renovation, is nearly 20 years.

* The total investment in buildings is very conservatively estimated to be nearly $650 million.

This brief chapter describes these findings in more detail.

Amount of Space Allocated to Science Education

The total stock of physical plant allocated for science education at the 39 institutions reporting data represents over 6.4 million gross square feet, and nearly 4.0 million net assignable square feet, contained in about 145 individual buildings. Applying the average figures to the institutions not providing data suggests a total stock for the 50 participating colleges and universities of 8.5 million gross square feet, 5.5 net assignable square feet, all contained in over 190 buildings.

The typical building measures nearly 34,000 square feet. Many buildings are shared by several departments, with biology and chemistry the most frequent companions. Only 10% of the buildings are jointly occupied by both a science department and a non-science department.

Of the net assignable square footage, about 43% represents laboratories, 21% classrooms, with the remainder used for offices, support services, and other activities.

From the planning perspective, it is important to understand the amount of space necessary for each science faculty member. These data reveal considerable variations among departments. Overall, each faculty member requires some 5,300 gross square feet. Not surprisingly the laboratory sciences lead the way, with Mathematics trailing by a substantial margin.

Condition of the Existing Physical Plant

Institutions were asked to rate the condition of the existing physical plant, to indicate the age of each building, and to provide information about major renovations. These data allow judgements to be formed about the state of the buildings in which science education takes place.

In general the quality of the buildings appears to be fairly good. Nearly 60% are rated as either in excellent or very good condition. However, about 30% are rated as good; 11% are rated as only fair or poor.

Perhaps more important than the number of building of various conditions is the absolute amount of gross and net square footage. In these terms the situation appears somewhat better. Almost 70% of the square footage, whether gross or net, is rated in excellent or very good condition. Less than 10% is rated either fair or poor.

Age of the Physical Plant

The generally favorable situation described above can be attributed to a renovation program of older buildings, rather than to significant new conscruction. The average age of the building stock is almost 50 years, with an effective age of about 20 years. Thus, a good deal of the existing stock has been renovated at least once.

New construction has been relatively rare. Only 12% of the buildings are less than 10 years old. Nearly one-half have stood to witness the 50th reunion of their earliest student occupants. Institutions have apparently chosen to undertake major renovation rather than replacement of their continually aging physical plant. This approach certainly reduces costs over the short-term, but poses serious long-term problems. The second, or third, renovation of a older building is unlikely to provide first-class, state-of-the-art laboratories or classrooms. Each renovation brings the building to an increasingly imperfect substitute for a new facility.

Replacement Costs

Institutions were asked to project the replacement cost of each building. The data provided lead to an estimated construction cost of approximately $105 per gross square foot. We believe this is a significant underestimate. The average construction cost of the eight buildings erected in the past five years was slightly under $150 per square foot. Adjusting for inflation gives a 1985-86 cost per gross square foot of roughly $175.

Taking the lower estimate, the calculated replacement cost of the science physical plant at all 50 institutions exceeds $861 million. Using the higher value yields a replacement cost of $1,435 million. This is clearly a very broad range, a range sufficiently broad for us to be uneasy with the adequacy of the underlying data, or perhaps with our estimation procedures. Regardless of the source of unease, it is plain that the conference institutions have a set of major agenda items with respect to the physical plant allocated to science teaching and research: to review the state of the existing building stock; to analyze effectively future needs; and, to develop a realistic schedule for building renovation and replacement.

Table IV-1. Building Profile 1985-86 -- Total Size

Each Institution	
Number of Buildings	3.9
Total gross sq ft	164,139
Total net sq ft	106,722

Size	Number Buildings	Total	Mean	Median
Gross sq ft	146	6,401,441	43,846	33,936
Net assignable sq ft	146	3,965,284	27,159	22,065
Percentage -- net to gross	146		61.9%	65.0%
Net Assignable sq ft				
Classrooms	137	606,788	4,429	3,356
Laboratories	139	1,520,861	10,941	6,971
Offices	137	370,844	2,706	2,100
Support services	137	518,627	3,786	2,550
Other	117	426,027	3,641	1,300
Total		3,443,147	25,503	16,277
Percentage Net Assignable sq ft				
Classrooms		17.6%	17.4%	20.6%
Laboratories		44.2%	42.9%	42.8%
Offices		10.8%	10.6%	12.9%
Support services		15.1%	14.8%	15.7%
Other		12.4%	14.3%	8.0%
Total		100.0%	100.0%	100.0%

Table IV-2. Net Assignable Space by Department

Net Assignable sq ft	Number Depts	Average Number Faculty	Average Gross sq ft per faculty	Average Net sq ft per faculty
Biology	34	580,901	17,085	16,826
Chemistry	27	436,478	16,165	15,133
Geology	22	194,854	8,857	7,766
Mathematics	19	98,527	5,185	4,410
Physics & Astronomy	29	348,756	12,026	9,000
Other Sciences	33	215,091	6,518	7,182
Non-sciences	18	156,793	8,710	5,175
Sq ft per faculty				
Biology	21	8	4,428	2,878
Chemistry	20	7	4,781	3,108
Geology	15	3	5,543	2,603
Mathematics	14	9	1,354	800
Physics & Astronomy	22	5	4,438	2,885
Other Sciences	10	4	6,130	3,984

Table IV-3. Condition of Physical Plant

Rating of Condition	Number	%	Cum %
Excellent	47	31.5%	31.5%
Very good	42	28.2%	59.7%
Good	43	28.9%	88.6%
Fair	15	10.1%	98.7%
Poor	2	1.3%	100.0%
Total	149	100.0%	

Rating of Condition	Number	Average Gross sq ft	Total Gross sq ft	Percent Gross sq ft	Cumulative Percent Net sq ft
Excellent	46	50,717	2,332,982	36.8%	36.8%
Very good	40	49,698	1,987,920	31.3%	68.1%
Good	42	35,608	1,495,536	23.6%	91.7%
Fair	14	28,564	399,896	6.3%	98.0%
Poor	2	62,617	125,234	2.0%	100.0%
Total	144	43,845	6,341,568	100.0%	

Rating of Condition	Number	Average Net sq ft	Total Net sq ft	Percent Net sq ft	Cumulative Percent Net sq ft
Excellent	45	29,385	1,322,325	33.7%	33.7%
Very good	42	31,760	1,333,920	34.0%	67.8%
Good	41	21,836	895,276	22.8%	90.6%
Fair	14	18,957	265,398	6.8%	97.4%
Poor	2	51,442	102,884	2.6%	100.0%
Total	144	27,159	3,919,803	100.0%	

Table IV-4. Age of Physical Plant

Rating of Condition	Number	Actual Age	Effective Age
Excellent	47	34.1	10.0
Very good	41	40.4	17.1
Good	43	58.8	28.0
Fair	15	80.2	25.5
Poor	2	85.5	85.5
Total	148	48.4	19.8

Age (Years)	Number	%	Cum %
0 - 5	8	5.3%	5.3%
6 - 10	2	1.3%	6.6%
11 - 20	34	22.5%	29.1%
21 - 30	19	12.6%	41.7%
31 - 40	13	8.6%	50.3%
41 - 50	6	4.0%	54.3%
51 - 100	59	39.1%	93.4%
> 101	10	6.6%	100.0%
Total	151	100.0%	

Effective Age (Years)	Number	%	Cum %
0 - 5	46	30.7%	30.7%
6 - 10	24	16.0%	46.7%
11 - 20	33	22.0%	68.7%
21 - 30	21	14.0%	82.7%
31 - 40	9	6.0%	88.7%
41 - 50	2	1.3%	90.0%
51 - 100	13	8.7%	98.7%
> 101	2	1.3%	100.0%
Total	150	100.0%	

Table IV-5. Estimated Replacement Cost

Rating of Condition	Number	Mean Repl Cost	Total Repl Cost
Excellent	46	5,222,868	240,251,928
Very good	38	5,269,321	200,234,198
Good	40	3,798,979	151,959,160
Fair	14	3,835,783	53,700,962
Poor	2	3,250,000	6,500,000
Total	140	4,619,733	646,762,620

Rating of Condition	Number	Derived Cost Per sq ft
Excellent	46	103
Very good	38	106
Good	40	107
Fair	14	134
Poor	2	52
Average		107

Chapter V

Investments to Maintain and Enhance Science Education at the Liberal Arts Colleges

What additional investments, above the substantial level of existing institutional commitment, will be required to maintain and enhance the vitality of science education at these national resources, the leading undergraduate liberal arts colleges?

In the 1985 Report we identified several areas requiring additional funding, but did not develop an estimate of the investment required to maintain the strength and vitality of science education at these institutions. We are now in a position to make an initial estimate -- capital investments exceeding one billion dollars over the next ten years. The investments fall into several general areas:

** Additional faculty positions to meet curricular needs and enrollment demands. $ 369 million

** Maintenance and enhancement effective teaching and research. $ 532 million

** Maintenance and enhancement of laboratories and classrooms. $ 150 million

These investments total $1.051 billion. The tables display the assumptions that have been made and provide detailed projections. We now discuss the assumptions and analysis.

The general approach is to estimate the incremental expenditures that must be made over the ten year period. Costs are of two sorts: a) capital expenditures for plant construction and renovation, and b) annual operating expenditures. To derive the overall estimate we calculate the capital that is required to support the operating expenditures.

This approach is predicated on the conviction that tuition and fee increases at these institutions are not likely to be sufficient to fund the increased investments envisioned here. Liberal arts colleges are highly tuition dependent: income from this source provides 60% to 80% of revenue. Tuition increases have exceeded inflation by several percent in each of the last several years. Increases above inflation are not likely to be continued. Thus, additional tuition revenue is not a probable source of funding for these investments. Neither is reallocation of internal resources. The sciences are already the most costly of the academic programs of liberal arts colleges. And there are

continual pressures to improve teaching in the arts, humanities, and social sciences. It is not likely that the colleges would choose to reallocate resources from these areas to the sciences at a rate much greater than at the present.

Thus, new resources must be found. We have chosen to compute the requirements in capital terms. This is obviously a simplifying assumption, but one we believe to be reasonable. Capital fund drives are an ever-present feature of the academic enterprise. New faculty positions and building programs are frequent objectives for such campaigns. Expendable gifts for current operations are another means of funding the needs outlined here. Gifts of this type, however, themselves represent a claim on capital, although they do not directly add to the capital base of the institution. They are a claim on the donors' existing or potential capital. Thus, we have chosen to present the analysis in capital terms.

Current conditions

These institutions presently deploy 1,600 faculty members in the sciences; their average compensation is roughly $45,000. These existing faculty; the present budget allocated to the sciences for library materials, travel, consumable supplies and material; and today's stock of instrumentation and physical plant, all represent the initial conditions for our estimate. It is evident that the conference colleges are highly productive. Past investments, by these institutions and by external agencies, have had an enormous impact. Scientific knowledge has been advance, leading scientists have been educated, and society's leaders exposed to scientific and technological issues. Here we attempt to estimate the investments that will be required over the next ten years to maintain and enhance their vitality and productivity.

Additional faculty positions to meet curricular and enrollment demand

1. Increase in positions -- We estimate that 166 new faculty positions must be added over the next 10 years. This estimate is derived from the experience of the past 10 years. There has been a 1.1% growth in faculty size each year. This number is somewhat higher than the estimates provided by those responsible for faculty personnel planning. A majority of institutions assume no growth in the size of either the student body, or the faculty; others assume modest growth. The composite estimate derived from this approach is 0.6% per year. We have chosen the historically based estimate, which itself may understate the true needs.

There are reasons to believe that both history and forecasts are based on actual or perceived resource limitations, not upon curricular need. More than a few colleges indicate they would like to add work in computer science, the neurosciences, immunology, molecular genetics, bio-organic and bio-inorganic chemistry, chemical physics, geophysics,

astrophysics, cosmology, and discrete mathematics, but have been unable to do so for a variety of reasons -- lack of well-qualified faculty, difficulties in reallocating positions from other divisions, and lack of money. Others indicate they would like to initiate interdisciplinary programs in areas such as the environmental sciences. Finally, several others describe the increasing use of part-time faculty, those on temporary appointment, and significant teaching contributions by support personnel as means of circumventing a "freeze" on new tenure-track faculty positions.

2. Faculty compensation -- We assume that total compensation, that is salary and benefits, averages $35,000. This is based upon a starting salary of $28,000 and 25% of salary devoted to benefits. The salary level is typical of an Assistant Professor with several years of post-doctoral experience, whether it be in teaching or research.

3. Support staff -- Each position that is added requires support staff (secretarial and technical) directly in the science departments. The ratio used here is representative of those institutions providing data in this area. The compensation figure is taken from national data for personnel in these categories, and is confirmed by data from a few colleges surveyed separately.

4. Books, materials and supplies -- Each new faculty position requires other forms of operating support -- library acquisitions (both monographs and serials), consumable laboratory supplies, travel funds, and the like.

5. Facilities -- New positions also require additional space for offices, classrooms, and laboratories. We assume that new construction will be required to provide this space, since most campuses have little if any "excess" space. The gross number of square feet for each additional position is estimated from current data. Maintenance costs are also included.

Maintenance and enhancement of effective teaching and research

1. Support for new faculty -- Faculty are hired each year not only to fill newly created positions, but also to replace those faculty that depart. The estimated departure rate of 4.7% is historically derived. Based upon the age profile of the current faculty, there is no reason to expect a change in one direction or another during the next ten years. Based upon an average faculty size of 1,691, about 94 new faculty members will be hired each year. Most colleges now offer very modest grants to launch a teaching and research career. We estimate that the average grant size should be increased by $30,000. The 1985 report recommended that research leaves should be provided during the probationary period since both mastery of teaching and the ability to maintain an independent research program must be demonstrated prior to tenure. These leaves might be awarded during the third or fourth year of appointment. Based upon existing resignation and reappointment rates, we estimate that 80% of a new appointment cohort might be eligible.

2. Competitive compensation -- As the competition for a decreasing number of Ph.D.s intensifies over the next decade, we expect that increased demand for talented scientists will tend to widen the existing compensation gaps between industry and academe and between universities and colleges. Colleges must ensure that compensation not be a significantly determining factor is the selection of institution in which a faculty member establishes or continues a career. Thus an increase in average compensation for science faculty, above the institutions' current planning assumptions, may well be necessary to prevent loss of faculty to other organizations. Our estimate of a 10% increase is admittedly speculative.

3. Student assistantships -- Student-faculty research is the hallmark of these colleges. Doubling the current number of student research assistantships, both during the academic year and summer months, would significantly improve both science education and faculty research. We assume that each faculty member could use effectively an additional two student assistant during the academic year and one during the summer.

4. Instrumentation -- The data on scientific equipment reveal both pressing immediate needs, which should be met by a one-time investment, and annual needs for new equipment as well as replacement of the existing stock. The immediate instrumentation requirements are taken directly from the data in this report. The annual needs are estimated from the five-year equipment projections.

Maintenance and enhancement of laboratories and classrooms

The aging physical plant will require both new construction and renovation if it is to serve the teaching and research needs of these colleges. The assumptions regarding the mix between new construction and renovation are based upon informed judgements of several physical plant professionals. The estimates of renovation and replacement costs are discussed in the chapter devoted to general physical plant issues.

Conclusion

The investments required to maintain and enhance the vitality of science education at these institutions are enormous. Despite their generally strong financial condition and sound resource base, the individual efforts of these institutions alone will not be able to meet the needs. They will require external assistance. The investment in scientific knowledge properly serves global needs; it is equally proper that it serve the national interest by strengthening science education and broadening the population that has scientific expertise. The faculty play a triple role -- they are active and effective research scientists, they are lucid and stimulating educators of future scientists, and they are important to providing the general scientific education of future leaders of society.

If the nation is to remain competitive, it must focus investments in quality. This report, and its predecessor, have argued that quality lies with the leading undergraduate colleges. They have demonstrated the capacity to educate the country's leading scientists, those able to contribute to scientific progress. Investment in their future is an sound investment in the nation's future.

SUMMARY OF INVESTMENTS

Additional faculty postitions	Annual Costs	Capital Requirement
Faculty salary and benefits	5,810,000	116,200,000
Support staff salary and benefits	1,155,000	23,100,000
Materials and supplies	1,660,000	33,200,000
Facilities construction	0	152,948,250
Facilities maintenance	2,184,975	43,699,500
Sub Total	10,809,975	369,147,750
Maintain & enhance effective teaching and research		
Starter grants	2,910,000	58,200,000
Probationary period research leaves	1,358,000	27,160,000
Competitive faculty compenstion adjustment	7,607,843	152,156,852
Student research assistants	5,917,211	118,344,218
Scientific equipment and instrumentation	7,062,697	175,905,236
Sub Total	24,855,750	531,766,306
Maintain & enhance laboratories and classrooms		
Replace outdated buildings	0	48,169,345
Renovate aging buildings	0	101,828,730
Sub Total	0	149,998,075
TOTAL	35,665,725	1,050,912,131

Table V-1. Additional Faculty Positions to Meet Curricular Needs and Enrollment Demands

Assumptions	
Increase in faculty positions (annual rate)	1.1%
Average initial salary and benefits	35,000
Operating Support required for each position:	
Support staff FTE	0.33
Average support staff salary and benefits	21,000
Books, materials, and supplies	10,000
Physical plant facilities:	
Gross sq ft for offices, labs, etc	5,265
Construction cost per sq ft	175
Maintenance cost per sq ft	2.50

Additional Positions	Total Number	Annual Cost	Capital Requirement
Faculty Members:			
Salary and benefits	166	5,810,000	116,200,000
Support Staff:			
Salary and benefits	55	1,155,000	23,100,000
Books, materials, and supplies		1,660,000	33,200,000
Sub Total		8,625,000	172,500,000
	Sq ft		
Facilities:			
New construction	873,990		152,948,250
Maintenance	873,990	2,184,975	43,699,500
Sub Total		2,184,975	196,647,750
Total		10,809,975	369,147,750

Table V-2. Maintenance and Enhancement of Effective Teaching and Research

Assumptions	
Average number of faculty	1,691
Average salary and benefits	45,000
Percent of faculty newly appointed each year	4.7%
Support for newly hired faculty:	
Average starter grant	30,000
Percent awarded probationary period leave	80.0%
Support for all faculty:	
Faculty compensation increase	10.0%
Student research assistantships per faculty	
Academic year	2
Summer	1
Student research assistants stipends:	
Academic year	1,000
Summer	1,500

New Faculty Support	Average Per Year	Annual Cost	Capital Requirement
Starter grants	97	2,910,000	58,200,000
Probationary Leave	78	1,358,000	27,160,000
New Faculty Support Sub Total		4,268,000	85,360,000
Additional Compensation	1,691	7,607,843	152,156,852
Student Assistants:			
Academic Year	3,381	3,381,263	67,625,267
Summer	1,691	2,535,948	50,718,951
Student Assistants Sub Total		5,917,211	118,344,218
Scientific Equipment: and Instrumentation:			
Immediate Needs			34,651,296
Annual Needs		7,062,697	141,253,940
Equipment Sub Total		7,062,697	175,905,236
Total		24,855,750	531,766,306

Table V-3. Maintenance and Enhancement of Laboratories and Classrooms

Assumptions	Gross Sq ft	Percent Replace	Percent Renovate
Physical Plant Condition:			
Excellent	3,129,240	0%	0%
Very good	2,666,407	0%	10%
Good	2,005,970	0%	33%
Fair	536,382	20%	80%
Poor	167,977	100%	0%
Total	8,505,976		

Physical plant costs (per sq ft):	
New construction	175
Renovation	75
Maintenance	2.50

Construction	Square Feet	Annual Cost	Capital Requirement
Replacement	275,253	0	48,169,345
Renovation	1,357,716	0	101,828,730
Total	1,632,970	0	149,998,075